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Summary Report in Support of Milestone 2.2.1/ 7

Human Performance Modeling Element

Developing Cognitive Models of Approach and Landing with Augmented Displays

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OVERVIEW

Milestone Objectives

This report provides a summary review of modeling activities conducted in support of the 2002 milestone objectives for the Human Performance Modeling (HPM) Element within the System-Wide Accident Prevention Project of the NASA Aviation Safety Program. The overall goal of the Level 3 NASA HPM Element is to develop and demonstrate cognitive models of human performance that will aid aviation product designers in developing equipment and procedures that are easier to use and less susceptible to error. The focus is on computational frameworks that facilitate the use of modeling and simulation for the predictive analysis of pilot behaviors in real-world aviation environments.

It should be noted that modeling pilot behaviors in the dynamic, time-critical, and complex domain of aviation (which often includes multiple interacting operators) presents a significant challenge for current human performance modeling architectures. (For an up-to-date and comprehensive review of human performance models see Leiden et al, 2001). This challenge is all the more difficult when the ultimate goal is the ability to effectively predict pilot errors, or the behavioral markers leading up to errors, that might arise during the operational use of new equipment concepts and procedures.

The 2002 modeling efforts described in this report follow a similar technical approach first utilized with success by the HPM Element in 2001. This approach involves applying different cognitive modeling frameworks to the analysis of a well-specified operational problem for which there is available empirical data of pilot performance in the task. In 2001, for example, five different modeling frameworks were used to analyze a series of land-and-taxi-to-gate scenarios taken from a high-fidelity full mission simulation study that produced an extensive data-set of pilot performance. Overall, this approach enables the HPM Element to assess and contrast the predictive ability of a diverse range of human performance modeling frameworks while encouraging the advancement of the modeling enterprise.

For 2002, the five modeling frameworks mentioned previously have been extended to the more complex problem of modeling pilot behaviors during approach and landing operations with and without the availability of a synthetic vision display. This is in accord with the HPM Element’s 2002 milestone objective (MS 2.2.1/7) calling for the development of cognitive models of an approach/landing scenario with an augmented display. Clearly, the relevance and usefulness of these efforts have much to do with the particulars of the operational scenario(s) selected for scrutiny, the quality of available task information and performance data, and the strengths and limitations of the individual modeling frameworks. Each of these will be discussed briefly below.

Task to be Modeled

A series of approach and landing scenarios were flown in a part-task simulation facility at NASA Ames Research Center by three commercial-rated airline pilots (see Appendix A for full details). The simulation was conducted in order to collect nominal data which would characterize pilot performance during the approach and landing phase of flight using conventional and augmented displays under both Instrument Meteorological Conditions (IMC) and Visual Meteorological Conditions (VMC) conditions. The test plan, rather than emphasizing statistical power, focused on a limited number of subject pilots operating across a variety of conditions from which performance estimates could be derived.

The PC-based simulator approximated the instruments and controls of a Boeing-757. The aircraft simulator was linked with a visual data base modeling Santa Barbara Municipal Airport and its surrounding terrain. The simulator consisted of four displays: viewed head-down were (1) a synthetic vision system (SVS) which provided a near-unity perspective view of terrain and cultural features ahead of the aircraft, overlaid with flight path predictor and other symbology, (2) a conventional flight display (Primary Flight Display and Navigation Display), and (3) a touchscreen software controls (Mode Control Panel, Flaps, Gear, and Speed Brakes); viewed head-up was (4) the out-the-window scene (OTW) presented on a large front projection screen. Control inputs were made via a joystick, throttle lever, and touchscreen software buttons. Experimenters acted as first officer and Air Traffic Control.

For all trials, subject pilots performed an RNAV (GPS) approach and remained fully coupled to the autopilot until reaching 650 feet Decision Height, at which point they took full manual control to either land or execute a go-around depending on trial conditions. Trials were run in 4 approach event conditions: **nominal**, **late runway reassignment** (requiring a side-step maneuver), **missed approach** (either no break in visibility or traffic on runway), and **terrain mismatch** (SVS display or Primary Flight Display not congruent with OTW scene at time of "break-out"). These event conditions were conducted with and without the SVS display and in VMC and IMC conditions where logical. This yielded 10 unique scenarios (as present below in Table 1) that were completed by each of the subject pilots.

The modeling objective was to utilize each of the five computational frameworks to model and simulate pilot behavior within the approach and landing scenarios flown in the part-task study. Of particular interest was the ability of a given model to predict changes in pilot attentional allocation, action selection, and timing associated with the use of a SVS display. Such differences could best be determined by comparing simulation results between baseline and SVS scenarios evaluated under the same event conditions.

Table 1. Test Conditions

	Display Configuration	Baseline	Baseline	SVS
	Visibility	VMC	IMC	IMC
Approach Event	Nominal Approach (nominal landing)	*Scenario #1*	*Scenario #4*	*Scenario #7*
Approach Event	Late Reassignment (side-step & land)	*Scenario #2*		*Scenario #8*
Approach Event	Missed Approach (go-around)	*Scenario #3*	*Scenario #5*	*Scenario #9*
Approach Event	Terrain Mismatch (go-around)		*Scenario #6*	*Scenario #10*

Available Information and Data-Set

The physical layout of the part-task simulation facility was documented (see Appendix B) so that the location, viewing distances, and subtended visual angle of informational elements could be computed. The documentation included descriptions of the symbology and functionality of displays and controls and the field of view provided by the SVS display.

Five types of data were collected during the scenario trials and made available for use in constructing the models: (1) time-referenced digital data concerning aircraft position and state, (2) pilot control inputs, (3) eye-gaze data, (4) video recordings from both an ambient room camera and eye-tracking camera with superimposed fixation cursor, and (5) post-trial questionnaires assessing workload and situational awareness.

The eye-tracking data, as an indicator of attentional allocation, are especially useful in differentiating pilot behaviors between baseline trials and SVS trials. Each trial was divided into segments and for each segment the total number of fixations, the average dwell time, and the percent of dwell time were calculated for six sceneplanes (or areas of interest – AOI). These were OTW, SVS Display, PFD, NAV Display, MCP, and Controls (flaps, gear, speedbakes, map scale). From this data pilot scan patterns within and across trials types could be compared and contrasted.

Apart from the empirical data derived from the part-task simulation, a detailed cognitive task analysis of B757 approach and landing operations was prepared (Keller & Leiden, 2002). This analysis covered all aspects of B757 operational knowledge from area navigation, approach procedures, flight controls, instrumentation, displays, and ATC communications down to a detailed event/task timeline of nominal procedures and the informational requirements for their proper execution. The document also noted potential off-nominal events and their triggers.

The empirical data and task information served a critical role in the model development process. This process required that the cognitive component of each of the frameworks had to be modified and expanded to include procedural and declarative knowledge regarding the approach and landing task, along with quantification of various parameters of related flight activities. Additionally, at some level of abstraction, representations of the flight deck (displays and controls), the aerodynamics of the aircraft, the physical environment (weather, terrain, and airport), and other interacting agents (ATC and first officer) had to be instantiated. Not surprisingly, the fidelity and sufficiency of these representational components are a major determinant of the validity of the resulting simulation output. These factors depend both on the quality of available task information and pilot performance data and the abstraction/representational skills of the modeler.

Model Descriptions, Approaches, and Results

From an initial review of past efforts in cognitive modeling, it was recognized that no one modeling architecture or framework had the scope to address the full range of interacting and competing factors driving human actions in dynamic, complex environments. As a consequence, the HPM Element sought to develop multiple modeling efforts. In 2001, five modeling frameworks were selected from a large group of responses to a call for proposals for computational approaches for the investigation and prediction of operator behaviors associated with incidents or accidents in aviation. This was, in essence, a request for analytic techniques that employed cognitive modeling and simulation. The peer-reviewed selection criteria included model theory, scope, maturity, and validation as well as the background and expertise of the respective research team.

Four of the five selected modeling frameworks (the exception being the A-SA model) were based on mature, validated, and integrative architectures which linked together embedded component processes of cognition with facilities to construct representations of the task-environment and to run simulations. (The A-SA model is a more limited-in-scope set of computational algorithms focused on attentional processes and the assessment of situational awareness.) All the modeling frameworks share these important characteristics: (1) they are generative, i.e., output results from the flow of internal model processes and is not “scripted”; (2) they have stochastic elements, i.e., no two simulation runs should ever be identical, even when all parameters are held constant; and, (3) they are context sensitive such that changes in the task-environment will bring about changes in simulation output.

Presented below in Table 2 is an overview of the modeling frameworks selected by the HPM element. Following the table is a brief description of the models and their origins, the implementation approaches which were used in the analyses, and the results obtained. A fuller account of each of the modeling efforts is provided in this report in Appendix A: Executive Summary of Modeling Teams.

Table 2. Overview of Selected Modeling Frameworks

Model	***Type***	***Distinction***	***Demonstrated Error Sources***
ACT-R/PM	Cognitive + Statistical Environment	Coupling of comprehensive low-level cognitive architecture with a principled methodology for statistically describing information environment	*Time pressure * Misplaced Expectations * Memory retrieval problems
Air MIDAS	Integrative Cognitive Perception & Environment	Demonstrated multiple cognitive agents interacting with each other and to their evolving context	* Workload *Memory Interference *Misperception
A-SA	Attention & Situational Awareness	Demonstrated computational algorithms for allocation of attention linked to algorithm assessing level of situational awareness in error generation	* Misplaced Attention * Lowered SA
D-OMAR	Integrative Cognitive & Environment	Provides framework to capture rich multi-tasking world of pilots reacting to environment for examining error	* Comm errors * Interruption & Distraction * Misplaced Expectation
IMPRINT/ACT-R	Cognitive + Task Network	Coupling of comprehensive low-level cognitive architecture with high-level task network	* Time pressure * Perceptual errors * Memory retrieval * Inadequate knowledge

<u>ACT-R/PM (Rice University & University of Illinois/San Jose State University)</u>
Atomic Components of Thought-Rational /Perception Motor is an experimentally grounded, open-source, low-level cognitive architecture developed at Carnegie Mellon University. ACT-R is based on the assumption that human cognition should be implemented in terms of neural-like computations on a very small time scale (50 ms –200 ms). A cognitive layer interacts with a perceptual-motor layer

to create activation levels which determine both knowledge accessibility and goal-oriented conflict resolution.

There were three major thrusts in the current ACT-R/PM modeling effort. The first was to close the loop – that is, to model both the human and the evaluated system as a complete dynamic system. The second thrust was to model the pilot as an adapted operator who is knowledgeable and experienced. Lastly, the focus of analysis was to be an explanation of how pilots deploy their visual attention and whether this is affected by the SVS display.

A fully-coupled simulation is not yet completely operational for this effort. However, a static approximation of the model was able to predict the distribution of visual attention to the six regions of interest across baseline and SVS scenarios with a moderate to high degree of correlation to the human data. Given these high-level results and the operational mechanisms of the model (bottom-up processes and context sensitivity), the model should allow predictions of attentional differences associated with small changes in the information display – providing valuable insights in assessing the performance effects of adding or removing specific pieces of information and the manner of presentation.

<u>Air MIDAS (San Jose State University)</u>

Air MIDAS is a version of *the Man-machine Integration Design and Analysis System* (MIDAS) developed as a joint Army-NASA program to explore computational representations of human-machine performance. Air MIDAS is driven by a set of user inputs specifying operator goals, procedures for achieving those goals, and declarative knowledge appropriate to a given simulation. These asserted knowledge structures interact with and are moderated by embedded models of cognition for managing resources, memory, and action.

Four areas of implementation paced the Air MIDAS modeling effort: (1) procedure development in which a series of rules were formulated to guide the responses of simulated pilots to the various environmental conditions; (2) perceptual system development to guide legibility and visual search/reading time; (3) scenario development based on the conditions of the part-task study; and, (4) model development which included equipment representation and scan pattern parameterization based on research data from Mumaw, Sarter, Wickens, Kimball, Nikolic, Marsh, Xu, & Xu (2000).

The completed Air MIDAS model was tested in three scenario conditions: nominal with no SVS, nominal with SVS, and late runway reassignment with SVS. Predictive validity was demonstrated by a strong correlation between dwell time distributions derived from the Air MIDAS model and those of the subject pilots in the two nominal scenarios. Moderate correlations were found in the runway reassignment scenario. Further refinements to procedural and visual processing sub-models should allow the Air MIDAS model to simulate, with good fidelity, pilot visual behavior across all scenarios types. This will provide a robust base from which to investigate performance issues associated with variations in information display and/or operational procedures.

A-SA (University of Illinois)

Attention-Situational Awareness is a computational model developed at the University of Illinois. The underlying theoretical structure of the A-SA model is contained in two modules, one governing the allocation of attention to events and channels in the environment, and the second drawing an inference or understanding of the current and future state of the aircraft within that environment. Four factors are used to compute attention allocation within a dynamic environment; salience, effort, expectancy, and value. In turn, attentional allocation modulates situational awareness.

The terrain mismatch scenarios, baseline and SVS were modeled. Each scenario was divided into four phases, distinguished from each other by potential changes in relevance and bandwidth of the visual environment. Situational awareness was operationally defined by the speed at which pilots became aware of a misalignment as determined by review of video tapes and transcriptions. Two “classes” of pilot behavior (“good” and “bad” SA) were determined.

Moderate to strong correlations were obtained between model predictions and corresponding pilot data for frequency of visual transitions and mean dwell durations across the four segmented scenarios phases. Correlations were generally higher without the “effort” parameter within the attention model (e.g., the effort of making longer scans does not appear to inhibit those scans). Model fit was better for the one “good SA” pilot than the two “bad SA” pilots, a discrimination that provides some validation of the model. Results support the promise of predictive assessment of situational awareness as an evaluation methodology.

D-OMAR (BBN Technologies)

The *Distributed Operator Model Architecture* was originally developed by BBN Technologies under sponsorship from the Air Force Research Laboratory. D-OMAR supports the notion of an agent whose actions are driven not only by actively seeking to achieve one or more goals, but also by reacting to the input and events of the world. It was designed to facilitate the modeling of human multi-tasking behaviors of team members interacting with complex equipment.

The present effort focused on building robust models of aircrew procedures for approach and landing using a baseline and SVS-equipped flight deck. Models closely followed the cognitive task analysis (Keller & Leiden, 2002) rather than the exact procedures as tailored for the part-task simulation trials. Consistent with a goal of examining error mitigation for two-person crew, each scenario contained a cognitive model for both captain and first officer.

Five scenarios were simulated: nominal condition (VMC), nominal condition

(IMC), nominal condition SVS, and late reassignment with and without SVS. The D-OMAR simulated aircrews readily accomplished the five modeled scenarios. For the baseline scenarios in VMC and IMC conditions, the modeled aircrews successfully executed the approach and landing using RNAV procedures much as the human subjects did in the part-task simulation. A similar pattern was found for the nominal approach in IMC conditions using the SVS-equipped flight deck. In the late reassignment scenarios, the simulated aircrews accepted the request by the tower controller to side-step to the adjacent parallel runway and went on to successfully perform the maneuver. Results demonstrate a solid foundation from which to construct and simulate increasingly complex scenarios aimed at probing modeled pilot behaviors for potential benefits as well as errors that might occur on the SVS-equipped flight deck.

<u>IMPRINT/ ACT-R (Micro Analysis and Design, Inc. and Carnegie Mellon Univ.)</u>
This hybrid framework integrates *Improved Performance Research Integration Tool (IMPRINT)*, a task network-based simulation tool developed by Micro Analysis and Design and *Atomic Components of Thought-Rational (*ACT-R), a low-level cognitive architecture developed at Carnegie Mellon University. This approach is meant to exploit the advantages of top-down control with the emergent aspects of bottom-up behavior for evaluating human performance in complex systems.

The IMPRINT simulation tool was used to construct the environmental and aircraft model which was linked with a pilot model instantiated in the ACT-R cognitive architecture. For this effort, the late runway reassignment scenario in baseline and SVS conditions was chosen for analysis.

A working model was completed which successfully executed landing scenario in both baseline and SVS conditions. Model sensitivity was then investigated in terms of four aggregate parameters: latency to look, latency to action, latency to listen, and ACT-R activation noise, a measure of stochasticity of the model’s decision making. The number of successful landings out of 100 simulation runs for each parameter setting was recorded. The resulting data show that the model is, in general, quite sensitive to timing parameters. The data also reveal the “brittleness” of successful performance, as just small parameter changes can lead to catastrophic results. Given the validity of the underlying model, these types of analysis can have important implications regarding error and safety.

Conclusion

Appendix A of this report is a compilation of Executive Summaries submitted by each of the modeling teams and provides a more thorough account of individual modeling efforts in 2002. Appendix B is a detailed report of the part-task approach and landing study from which scenarios and performance data were utilized. Looking ahead, modeling efforts will be centered on meeting the HPM Element’s next milestone objective, 2.2.1/9, which reads as follows:

Advanced cognitive models of multiple diverse scenarios: *Develop cognitive error models with consistent treatment of multiple scenarios for a single augmented display*.

This milestone objective continues the HPM element's strategy of progressive development of cognitive models into increasingly complex real-world applications.

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Appendix A: Executive Summary of Modeling Teams

Developing Cognitive Models of Approach and Landing with Augmented Displays

ACT-R/PM (Byrne and Kirlik)
Approach and Landing, Modeling the Human in the Loop with ACT-R A-2

Air MIDAS (Corker, Gore, Guneratne, Jadhav, and Verma)
Human Performance Modeling Predictions: Synthetic Vision Systems and Reduced Visibility Operations A-10

A-SA Model (Wickens, McCarley, and Thomas)
Attention-Situation Awareness (A-SA) Model Interim Report A-19

D-OMAR (Deutsch and Pew)
Modeling the Baseline and SVS-Equipped SBA Approach and *Landing Scenarios* A-26

IMPRINT/ ACT-R (Archer, Lebiere, Schunk, and Biefeld)
Modeling of Pilot Tasks in the Approach and Landing Phase of Flight using IMPRINT and ACT-R A-32

Approach and Landing, Modeling the Human in the Loop with ACT-R

Michael D. Byrne & Alex Kirlik

Rice University & University of Illinois/San Jose State University

Executive Summary Project Report: December 2002
#NDD2-1321, Integrated Modeling of Cognition and the Information Environment.

1. Description of Modeling Effort

1.1 Overview of Analysis

One of the many lessons we learned from our previous work on the taxiing model is that the details are critical, particularly for an architecture at a fine grain of temporal resolution, such as ACT-R. Thus, our focus has been on laying an appropriate foundation for the modeling effort. We have eschewed shortcuts for higher fidelity. While this has slowed certain aspects of our progress, we believe this will pay off later. Our approach has been to try to understand the major sources of both insight and constraint in generating our models. We have identified four such sources:

1.1.1 Task Analysis. Our first order of business was to try to understand the task at a detailed level. This is relatively challenging for this task because there is little overt action taken by the pilots in these scenarios; it appears on the surface to be primarily a supervisory control task, at least until the pilot takes manual control. However, the task is more complex than just that. To understand it, we have relied on three primary sources of information: the task analysis information collected and supplied by NASA Ames; other related work in the human factors of aviation; and conversations with our subject matter expert (SME). We have synthesized these into the ACT-R formalism, an example of some of the control structure appears in Figure 1.

1.1.2 Data Analysis. The Ames team has provided us with a substantial amount of detailed information. The dearth of traditional overt behaviors (e.g., button pushes) means that nearly all of the interesting data guiding our modeling effort is the eye-tracking data. Furthermore, we believe that this is the most critical data to evaluating the impact of the SVS, since the primary function of the SVS is to provide visual information to the pilot. We have broken down the data so that we can look at various metrics (e.g. total dwell time, number of fixations) by region of interest and phase of flight. We are in the process of expanding the analysis to look at transition probabilities as well.

1.1.3 ACT-R. The ACT-R architecture provides a great deal of constraint as well. Working within the parameters of the architecture sets certain boundaries and delimits scope, in particular, it means that we are modeling the task at a highly detailed level of analysis. ACT-R provides end-to-end modeling of the human operator side of the human-in-the-loop, from basic visual and auditory attentional operators to complex cognition and back down to basic motor movements.

1.1.4 Extant accounts. Because the eye-movement data will be the primary focus of the modeling effort, we have examined other data and models in the allocation of attention domain in the human factors literature (e.g., Senders, 19xx; Wickens, et al. {ref}). These are high-level (relative to ACT-R) accounts of how operators choose which objects to visually sample and at what frequency. We believe that these accounts provide a useful high-level starting point; we hope to provide the explanation for how these high-level phenomena emerge from a combination of task and environmental constraints and relatively low-level cognitive-perceptual capabilities.

1.2 Focus and Intent of Modeling Effort

We have three major foci in the present effort:

1.2.1 Closed loop. One of the things which distinguishes an analysis at the level of a cognitive architecture such as ACT-R is that it is possible to close the loop of the human-machine system. That is, both the human and the evaluated system are modeled dynamically and in detail, and the two sub-models are coupled, yielding a model of the complete dynamic system. Work on the taxiing model revealed that fidelity of the machine/environment model was critical in understanding the performance of the human model; thus, we are continuing with this.

1.2.2 Adapted pilot. Present efforts are based on modeling a pilot who is both knowledgeable about the task and well-adapted to it. We are neither modeling novice pilots or the acquisition/development of piloting expertise. However, we believe that this has certain implications which we may want to relax later, see the section on later efforts for more details.

1.2.3 Attention allocation. As mentioned previously, we believe the primary phenomenon to be explained here is how the pilots deploy their visual attention across the visual array and how this is (or is not) affected by the SVS. While this appears straightforward, there are some subtle issues here which we are exploring. For example, the ACT-R model produces timestamped individual shifts of visual attention (saccades) to small targets; we believe it is a mistake to attempt to map these directly to the individual saccades made by the pilots. Rather, such data can be analyzed at different levels of abstraction. For example, one could reasonably be interested only in more gross performance measures, such as the proportion of fixations on each scene plane, for which we have human data and can generate model data, which can be analyzed with the same software we developed to the analysis described in section 1.1.2. An important research question is What level of analysis is appropriate to guide design decisions?

1.3 Detailed Implementation Approach

Many of the details of the implementation have already been discussed. The primary inputs to the cognitive model come from the task analysis; this is the source of the procedural knowledge and the bulk of the initial declarative knowledge given to ACT-R. The output of the model is a timestamped series of behaviors including individual attention shifts, speech output, button presses, and the like. The primary point of comparison for the model output is the human eye-tracking data, which can be examined at various levels of abstraction. One piece that has not been described in much detail thus far is the other half of the simulation: the simulation of the aircraft.

We have mocked up the primary displays (NAV, PFD, MCP, etc.) in the language of ACT-R so that it can directly view those pieces of the display. However, this is not enough; ACT-R requires a dynamic environment with which to interact. For instance, if the flap setting is changed by the model, there are certain expectations about downstream effects on flight performance. To make those happen properly, a simulation of the airplane is required. We have purchased the commercial software package X-Plane (note that X-Plane has been certified by the FAA for training pilots, see http://www.x-plane.com/FTD.html) for this purpose and are in the process of linking X-Plane to ACT-R. This is not trivial; we are writing a network interface (based on UDP) between the two programs from the ground up. X-Plane natively supports sending certain kinds of information such as altitude and heading via the network interface, but other things cannot be sent, including the view out the window. This represents something of a problem since the ACT-R model needs something to see out the window (and on the SVS). However, we believe this problem can be solved relatively straightforwardly by abstracting out only what the model would need to look for when it looks. For example, because we know the plane s absolute position and orientation with respect to the airport, we can determine whether whatever piece of information the model was seeking would be available. This task-oriented solution may have uses in other domains as well.

In addition, we have to supply X-Plane with the aircraft specifications (a 757) and the appropriate approach/navigation and FMC programming (e.g., fix points) for Santa Barbara. Fortunately, the 757 specifications and the airport and geography for Santa Barbara were freely available and could simply be plugged in. Figure 2 presents a diagram describing the system. System runs will involve initializing both ACT-R and X-Plane appropriately, running them, and collecting a trace of the output. X-Plane is designed to run in real time, so generating multiple simulation runs will be time-consuming. (However, there may be some workarounds for this and we are hoping to get X-Plane to run 2x or 4x real time.)

2. Findings

Because the fully-coupled simulation is not yet completely operational, our findings are currently somewhat preliminary. However, we believe that we have still made substantial progress and, more importantly, gained significant insight. First, our initial data analysis shows that the SVS does indeed affect attention allocation, and that this is conditioned on phase of flight. Consider Figure 3, which shows the percentage of the fixations made by region of interest (ROI) for flight phase 1 (start to initial fix). Note the similarity between the non-SVS and SVS conditions. Contrast this with Figure 4, which presents the same data for phase 3 (final fix to decision altitude). Note how the pilots make little use of the SVS in phase 1, but in phase 3 their eyes are aimed at the SVS nearly a third of the time. Note also that the SVS is not simply a proxy for looking out the window in phase 3; pilots rarely look out the window at this phase. Instead, pilot look at the SVS and look less at the PFD and NAV displays.

At a high level, the model has a clear story for these data. The model predictions are based on the number of times a piece of information must be found and where the model will look for that piece of information. The model proportion presented here is simply the number of times attention will be directed to any particular display divided by the number of times attention will be directed to all relevant displays. When a piece of information could be found on the SVS as well as somewhere else (the PFD or OTW), the weak assumption was made that the model would get that information from the SVS 1/2 the time and from the other source (PFD, OTW) the other half of the time.

The following table presents the overall, that is, not conditioned by phase of flight, data for both the human data and the model:

Region of Interest	*Data, no SVS*	*Model, no SVS*	*Data, with SVS*	*Model, with SVS*
NAV	0.39	0.30	0.28	0.27
PFD	0.38	0.44	0.33	0.30
MCP	0.07	0.19	0.03	0.20
OTW	0.03	0.07	0.03	0.03
SVS	-	-	0.21	0.20

This is essentially a static approximation of the dynamic system, which may vary from this somewhat in final form. However, the initial analysis is encouraging; the fully-dynamic model should certainly be able to capture the patterns found in the data.

What it is important to note here is that the predictions for the SVS condition, in particular, are sensitive to local properties of the display. We currently use a rough estimate that if an item is available on the SVS then the model will look at the SVS half the time; this is currently a baseline assumption. In fact, if the model needs to look for a particular piece of information that is available in multiple locations (e.g., altitude, which is on both PFD and SVS), where it will look will be conditioned on where it is currently looking. ACT-R models are sensitive to local costs, and looker further away takes longer, so the model will prefer to look for the altitude on the SVS if it is already looking on the SVS.

Essentially, we see high-level properties of the model, such as its overall attention allocation behavior, as emergent from the combination of lower-level mechanisms and the structure of the task and environment. This should allow us to make predictions about even very small changes of the display; for instance, the model predicts that the overlay of airspeed and altitude on the SVS is a major factor in determining the degree to which the pilots will look at the SVS.

3. Implications

Given the previous section, some of the predicted implications for SVS design are fairly straightforward. For example, at the HFES conference this past October, a field test of an SVS system was described. This SVS, however, was different from the SVS used in the Ames study for which we have data. Specifically, the SVS which was field tested had altitude and airspeed displayed in moving bars (the way they are displayed on the PFD) overlaid, which the modeled SVS does not. Our model would suggest that this is will lead to increased SVS usage because it makes rate of change of altitude and airspeed easier to obtain. In general, the model predicts that the symbology overlaid on the SVS is a critical factor in determining how often pilots will look at it. Furthermore, the model should be able to make predictions about the effects of adding or removing specific pieces of information.

We have gained other insights as well. First, even from the three subjects for whom data was provided by Ames, there were substantial individual differences, particularly at the more local levels. Because of this, and because such differences are likely to exist in the wider population of potential SVS users, we believe it would be a huge mistake to try to fit every aspect of these individuals behaviors. Attempting to fit the complete scan path for any one subject would not only be laborious, it would almost certainly be an instance of fitting a great deal of noise. Just because the model is capable of generating fine-grained behavior does not mean that should be the basis of evaluation; rather, we believe more abstracted measures will do a better job of smoothing out individual difference noise and thus should constitute the model s criteria. We are not yet certain exactly what the best measures should be, but we believe this is an important question that we likely would not have considered without the combination of our model and the data we have in hand.

4. Lesson Learned

4.1 Progress and Advances

While there is still much more work to be done and many things to learn, we believe we have generated several advances. First, the model is not tied to any of the specifics of the scenario. If the FMC is pre-programmed correctly and the model is given relatively little knowledge about the airport, the model should be able to run through the approach fixes for any approach and landing scenario, as long as no serious maneuvers are required. This could potentially be a win for future aviation safety research. Second, the network interface we are developing could have wide applicability, as many simulation environments (e.g. video games) use similar communication protocols; this may make it possible to connect ACT-R to a wider range of environments. This should be particularly powerful when combined with the task-oriented solution we have generated to the out-the-window vision problem.

In addition, we believe that we may have some leverage on some other high-level and abstract human factors constructs, such as situation awareness. There is no box or section of the ACT-R architecture that one could point to as being situation awareness. Rather, we have observed that the model has to keep a number of pieces of information available at various times (some things, like altitude, all the time); the accessibility of the set of needed information about the aircraft s state might be termed the model s situation awareness, but it is not a unitary thing. It is both distributed, in that it lives in multiple declarative memory elements, and dynamic, in that different pieces are needed and refreshed by checking the environment at different rates.

4.2 Challenges

Doing a detailed simulation of human-in-the-loop performance in a domain this complex is fraught with challenges; many of them have already been described. Probably the biggest thing that could have gone more smoothly and should be considered for future efforts is to give the modeling teams direct access to the simulator code; the X-Plane solution we believe will ultimately work, but it has been slow going. However, it is clear that lessons were learned in the earlier taxi modeling and we would put a much higher priority on any future work providing data as rich as the data we received for this effort.

4.3 Future Directions

Obviously, there is still a great deal of work to be done to completely close the loop; this is our top priority. Once that is done, we hope to explore the design space for the SVS a little, and will try variants of the current SVS symbology to assess their impact on the model s performance. We are hoping this will lead to greater insight into the evaluation of SVS technology.

In addition, we would like to explore de-adapting the task analysis. One of the issues with many task analyses as they currently stand is that they include the operator s attunement to the constraints of the environment and may not be terribly useful at predicting how performance would be if the environment were different. We hope to produce a more abstracted model, possibly further away in capturing current performance, but with an eye toward predicting the effects other novel changes to the cockpit environment.

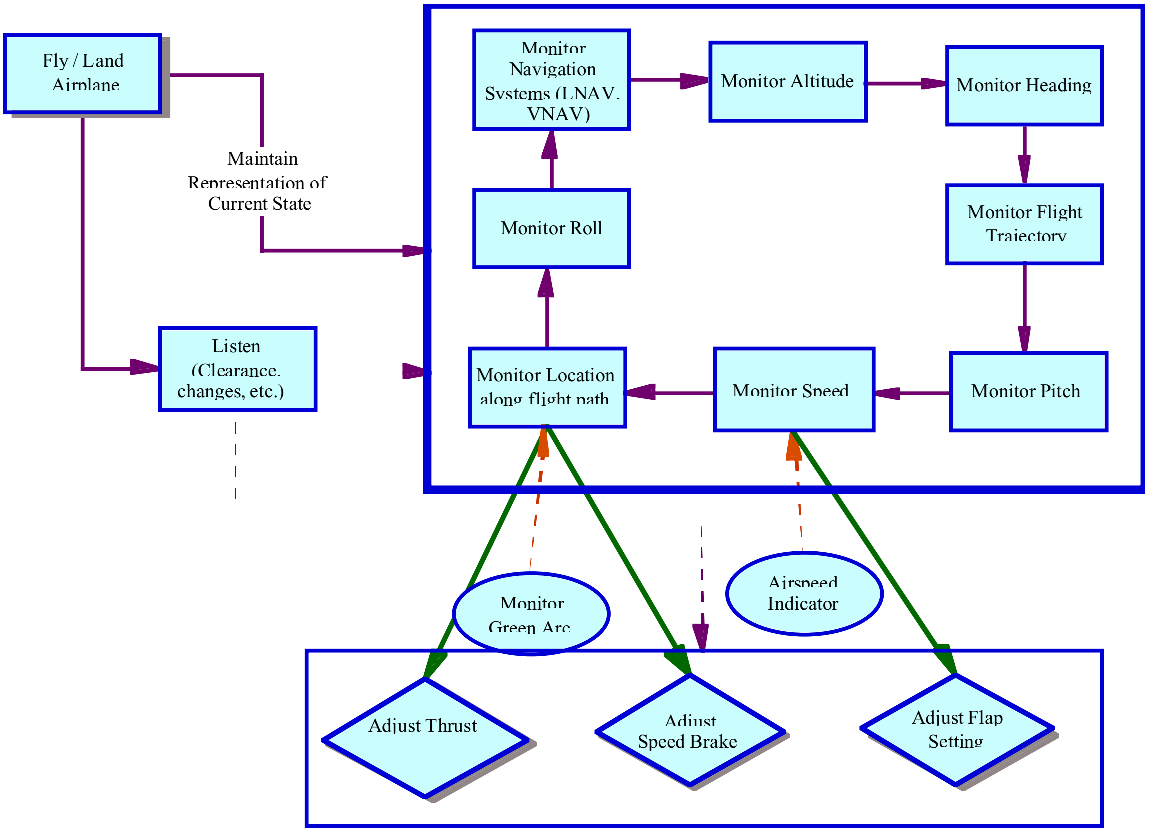

Figure 1. Section of the task analysis flow of control.

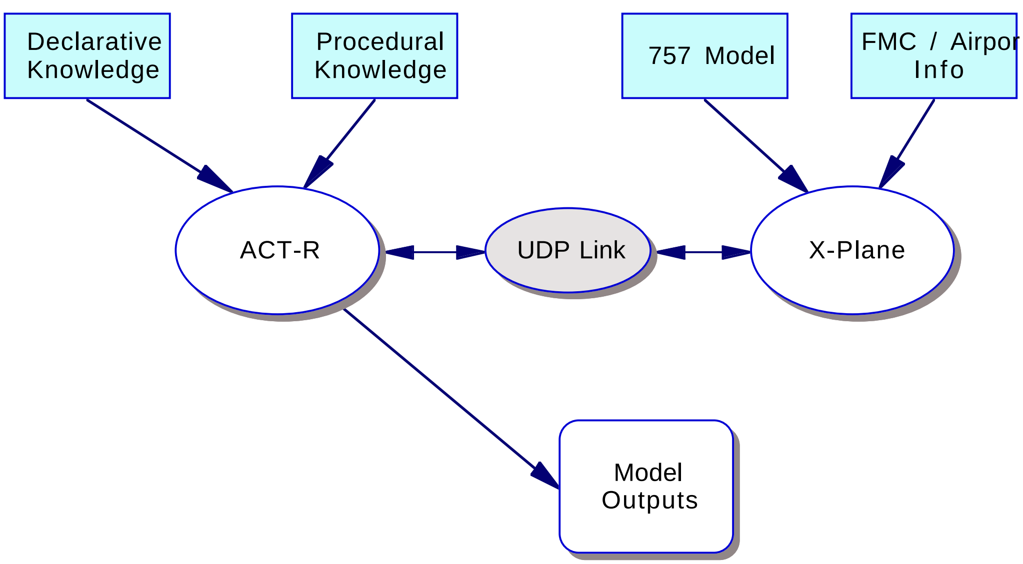

Figure 2. System overview.

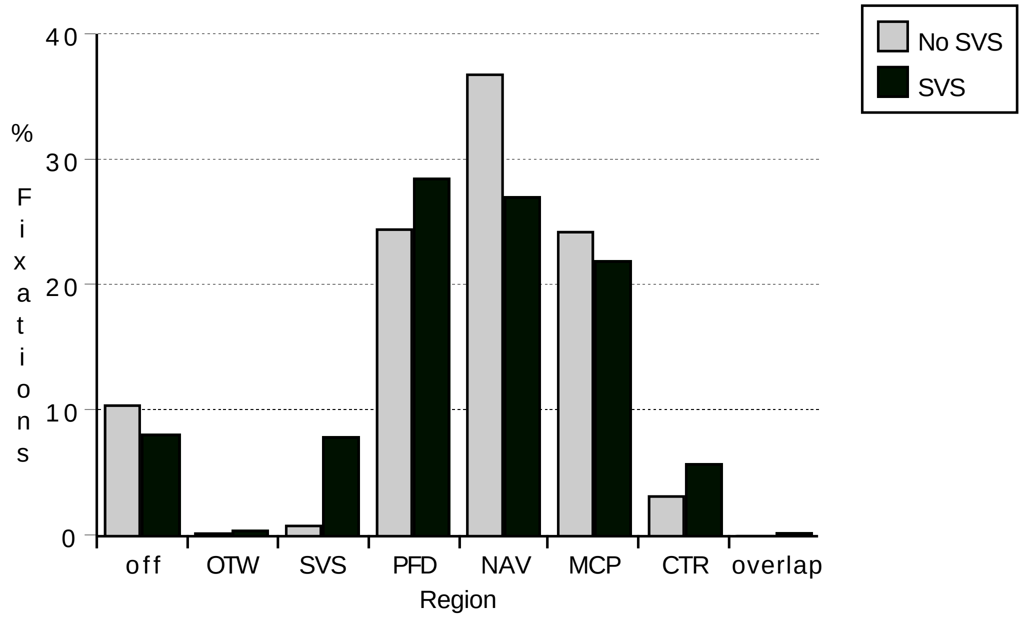

Figure 3. Percentage of fixations on different regions of interest, both with and without SVS, for phase 1 of flight (start to initial fix). off an d overlap indicate fixations where region data were unavailable or ambiguous.

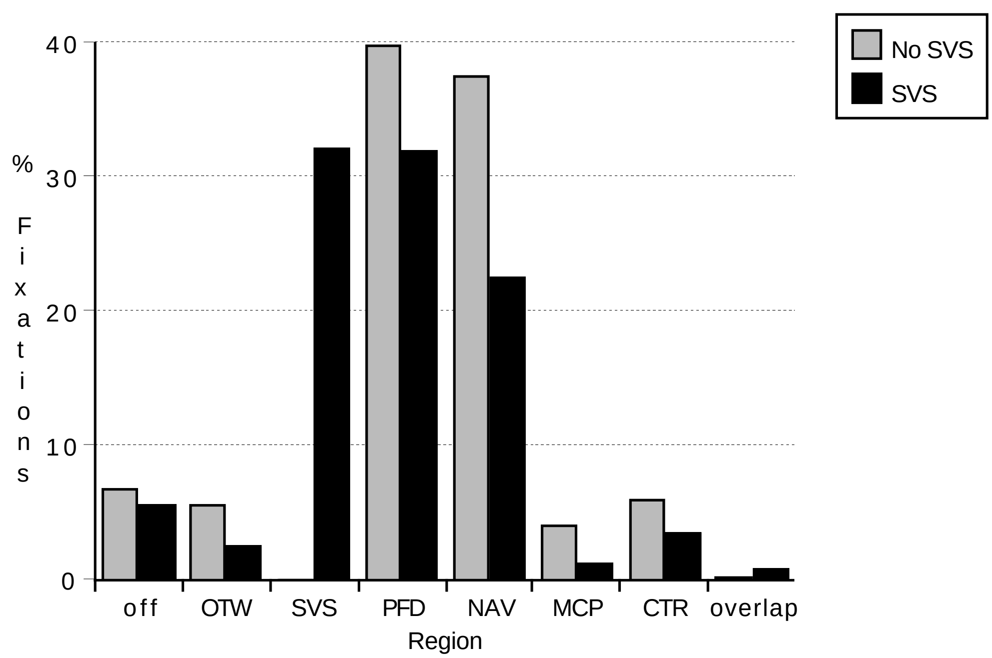

Figure 4. Percentage of fixations on different regions of interest, both with and without SVS, for phase 3 of flight (final fix to decision altitude). off an d overlap indicate fixations where region data were unavailable or ambiguous.

Human Performance Modeling Predictions: Synthetic Vision Systems and Reduced Visibility Operations

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NASA GRANT #: 2-1307; Grant Name: Human Performance Modeling

Description of Modeling Effort

The San Jose State University Human Performance Modeling Team (Team HAIL) undertook this human performance modeling research effort to predict the performance of operators using the Synthetic Vision System (SVS), under development by the NASA Aviation Safety Program for navigation during reduced visibility. We report on that process and the progress here.

1.1 Procedure Development

The SJSU team needed to specify the environment to be modeled. Therefore, Team HAIL gathered information from the NASA HPM Organizing Team to generate an understanding of the operational concept associated with the SVS on approach to a general airport environment. Background information was gathered from two tracks — one informational track based on procedural analysis and the second track based on part task simulation data sources. NASA Langley Research Center (LaRC), Honeywell, Micro Analysis and Design (MA&D), Boeing Commercial Aircraft Company and the University of Illinois provided the analytic data. The part task simulation data came from a human-in-the-loop (HITL) simulation that was completed by NASA Ames Research Center in FY 2002. These data were used to guide model development as will be described. The operational environment was used to develop a series of rules to guide the responses of the simulated agents to the various environmental conditions. Team HAIL produced general human performance models representing both pilot-flying (PF) and pilot-not-flying (PNF). The human performance capabilities represented are applicable to many performance domains and were driven in this case by the procedures associated with descent and approach. In order to accommodate analysis of the impact of the SVS on flight crew performance, further development of the perceptual model in the Air MIDAS was also undertaken.

1.1 Perceptual System Development

Team HAIL was aided in perceptual function development through collaboration with a vision modeling expert from New York University, Dr. Michael Landy. Dr. Landy developed mathematical equations to guide perceptual and attentional behavior within the human visual system. The full set of algorithms provided were examined and those most appropriate to the current SVS task were selected for implementation (Landy, 2002). We anticipate further development of the perceptual model in year two of the project. The standard Air MIDAS model of visual performance was augmented to include the affect of contrast legibility and visual search/reading time. Air MIDAS is now able to implement a reading rate model based on information presented on a display using visual angles and character size which is important in determining the effect of augmented visual information from the SVS display.

1.1 Scenario Development

The SJSU team developed scenarios to elicit emergent behaviors on approach and landing to an airport. The scenario procedures were based on the NASA Ames part-task simulation process. Scenarios were developed for both the baseline operations condition of the human in the loop NASA SVS simulation and the advanced SVS operations conditions (with side step) to generate predictions of time to complete various procedures required to safely land a commercial aircraft. The aircraft performed a parallel approach to the landing strip at Santa Barbara Airport flying under Instrument Meteorological Conditions (IMC) with current day technologies or future cockpit configuration (SVS display). The IMC approach used the RNAV or GPS precision style of approach (NASA HPM, 2002). The baseline condition was an approach to the Santa Barbara Airport under current day rules of flight with current day procedures (not using advanced displays) while the future SVS condition incorporated information displays to improve the awareness of the flight crew relative to the baseline condition.

1.1 Model Development

Team HAIL developed a representation of the equipment and an augmented visual behavior model that incorporated visual scanning performed by pilots. The visual scan patterns were developed to represent the mental model and the cognitive strategy of the operator (Wickens, 1999). The visual scan patterns (dwell fixations and dwell durations) were seeded with the scan pattern data taken from the research data of Mumaw, Sarter, Wickens, Kimball, Nikolic, Marsh, Xu, & Xu (2000). The NASA HPM Organizing Team provided the aircraft state data that was used to populate the equipment representation in the model. A rudimentary accuracy function was also modeled that updated the simulated agent s internal representation of the world (equipment) based on the rule that the agent had spent enough time looking at it. This based on the changes in the world the simulated agent selected and performed appropriate tasks and goals. The flow of information into the Air MIDAS operator and the relationship that exists with the environment can be found in Figure 1.

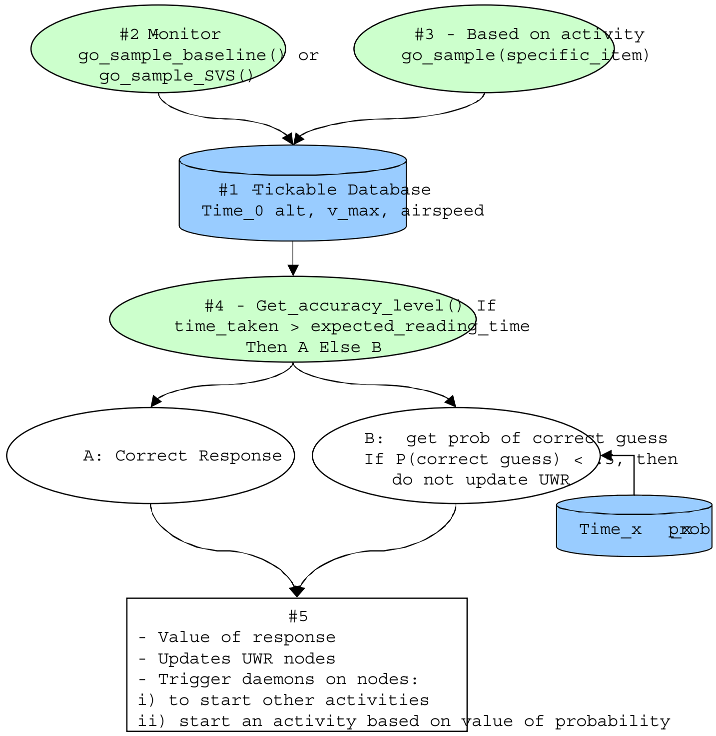

Figure 1. Information Flow into Air MIDAS.

Although not formally part of the NASA exit criteria for the current fiscal year, Team HAIL followed the recommended model development process and conducted both verification and validation phases of the emergent simulation data generated by Air MIDAS. Verification was conducted throughout the development process. Verification is concerned with the operation of the model and insures that the model performs, as the development team would expect (Law & Kelton, 2000; Balci, 1998). An informal verification process was followed during model development with reference to the model calibration data form Mumaw, et al. (2000). Team HAIL used the Mumaw, et al. (2000) research data supplied by the NASA HPM Organizing Team to parameterize the models procedures and information seeking behavior in all the three scenarios. As the Mumaw et al. (2000) study was conducted without an SVS system, SVS fixation data were not available from that study.

After model development, a simulation was run on approach under baseline without SVS, baseline with SVS and side-step with SVS. A strong correlation was found between the Mumaw, et al. s (2000) percent of fixations data and the Team HAIL Air MIDAS percent of fixations data across all scenarios with Scenario 4 (baseline) r = 0.9936, Scenario 7 (baseline with SVS) r = 0.9955, and Scenario 8 (SVS w/sidestep) r = 0.9948. Figures 2 and 3 demonstrate the respective elements within the flight crew agent s scan pattern of the crewstation and external environment. These data indicate that the procedural and visual sampling behavior that is encoded and run through the simulation replicate the source data of human performance. This is verification that the model behaves as designed and doesn t corrupt the seed human performance data.

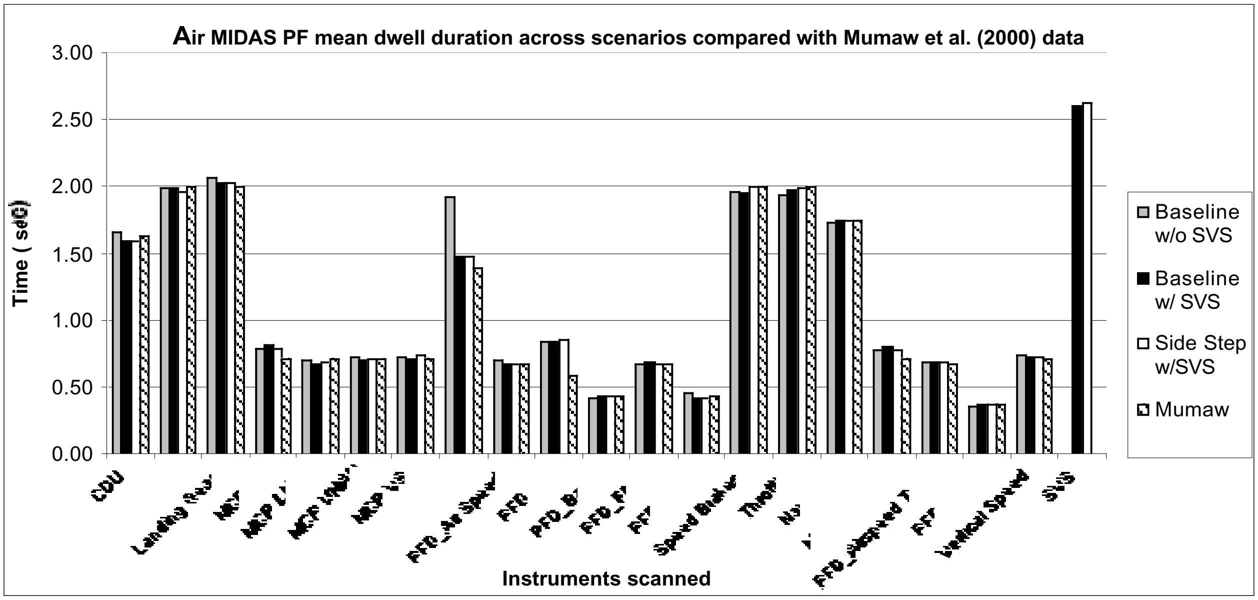

Figure 2. Air MIDAS mean Pilot Flying (PF) dwell duration compared with Mumaw, et al. (2000) HITL data across scenarios.

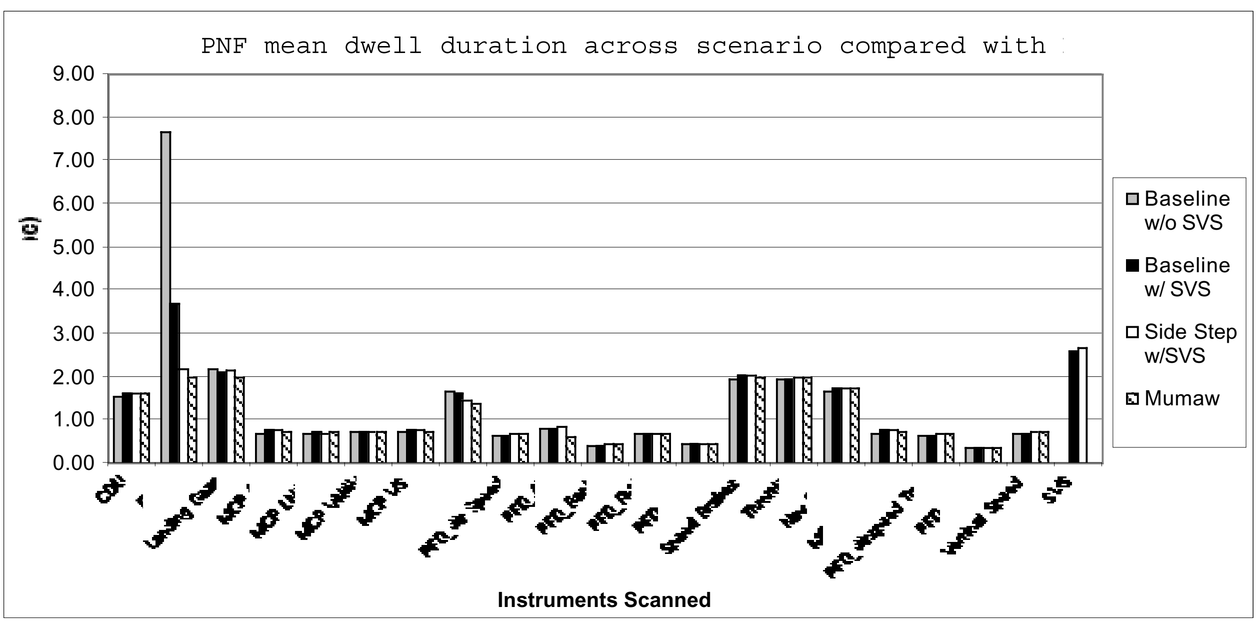

Figure 3. Air MIDAS mean Pilot Not Flying (PNF) dwell duration compared with Mumaw, et al. (2000) HITL data cross scenarios.

The predictive validity of the Air MIDAS model was also tested by running the model through three simulation conditions based on those undertaken by NASA HPM part-task experiment. Validation for appropriate visual scanning behavior on the model s part was examined by looking at the model-generated dwell frequency compared to the human flight crew dwell frequency patterns that were measured using eye movement sensors in the part-task simulation. It was found that the NASA HPM (2002) SVS simulation percent of fixations required in completing an approach and landing correlated with the Air MIDAS performance data across all scenarios. The correlation between the NASA part-task simulation and the Air MIDAS percent of fixations data Scenario 4 (baseline) r = 0.7608, Scenario 7 (baseline with SVS) r = 0. 8782, and Scenario 8 (SVS w/sidestep) r = 0. 5538. An examination of each of the respective model-human dwell percentage locations comparisons by scenario can be found in the following three figures.

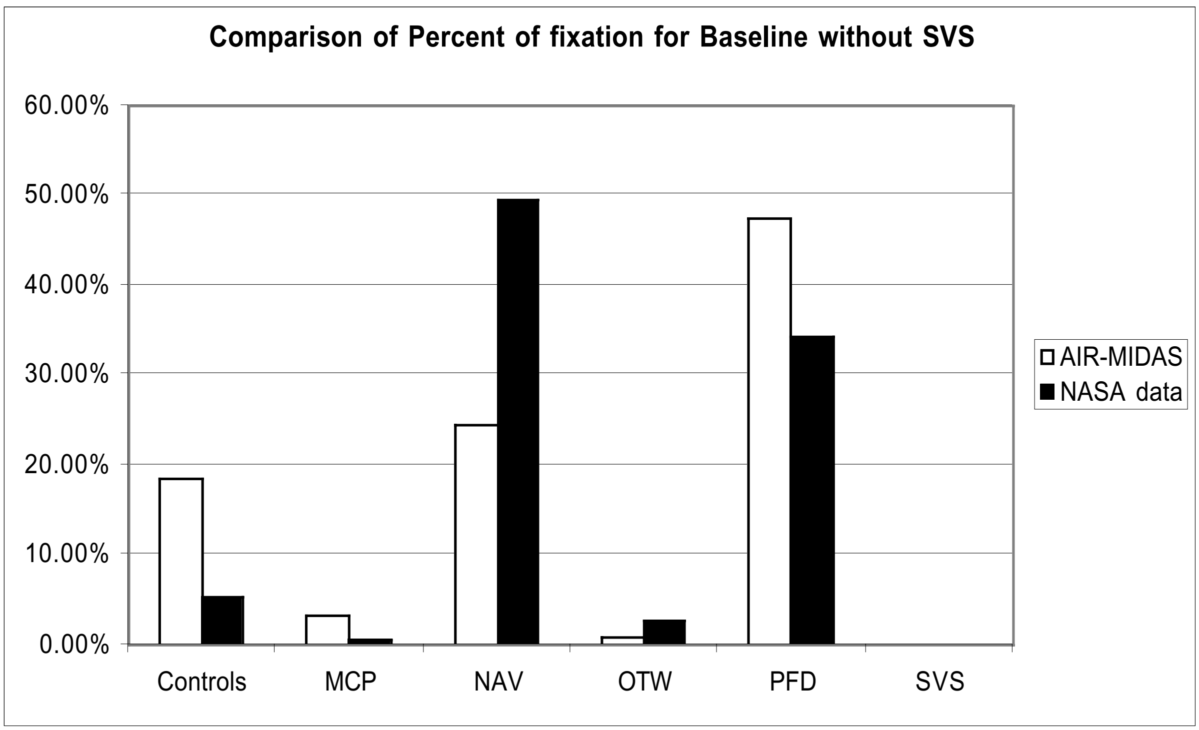

Figure 3. Model-Human Comparison of Baseline (no SVS) Fixation Percentage Location.

Figure 4 demonstrates that the Air MIDAS model predicted slightly higher fixation on the controls, the MCP and the PFD than did the human data produced by the NASA HPM (2002) SVS simulation. The Air MIDAS model predicted lower dwells on the Navigation Display and the OTW scene than did the NASA HPM (2002) SVS simulation. This suggests that the rules guiding human performance are different than those guiding the model s performance. The human pilot flies to a larger extent using the information on the Navigation Display given their fixation pattern than does the Air MIDAS pilot while the Air MIDAS pilot fixated on the Primary Flight Display to a larger extent than does the NASA pilot. No SVS fixations were found as there were no SVS displays in this scenario.

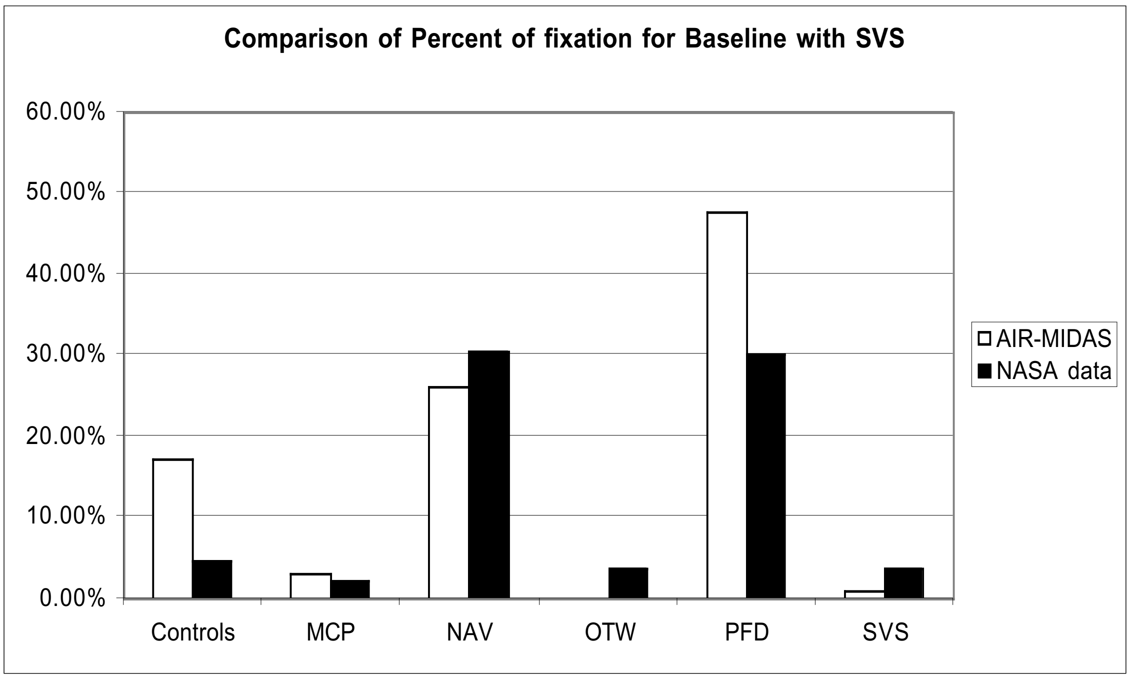

Figure 5. Model-Human Comparison of Baseline (With SVS) Fixation Percentage Location.

Figure 5 demonstrates that the Air MIDAS model predicted slightly higher fixation on the controls, the MCP and the PFD than did the human data produced by the NASA SVS simulation. The Air MIDAS model predicted lower dwells on the Navigation Display, the OTW scene and the SVS displays than did the NASA HPM (2002) simulation. This suggests that when flying with the SVS display, the NASA HPM (2002) flight crews looked at the SVS information to a greater extent than did the human performance model. These differences and their possible sources are discussed in detail in our final report. In short summary however, the human flight crew received PFD information form overlays in the SVS and the Air MIDAS model required looking at the PFD (not the SVS) for that information.

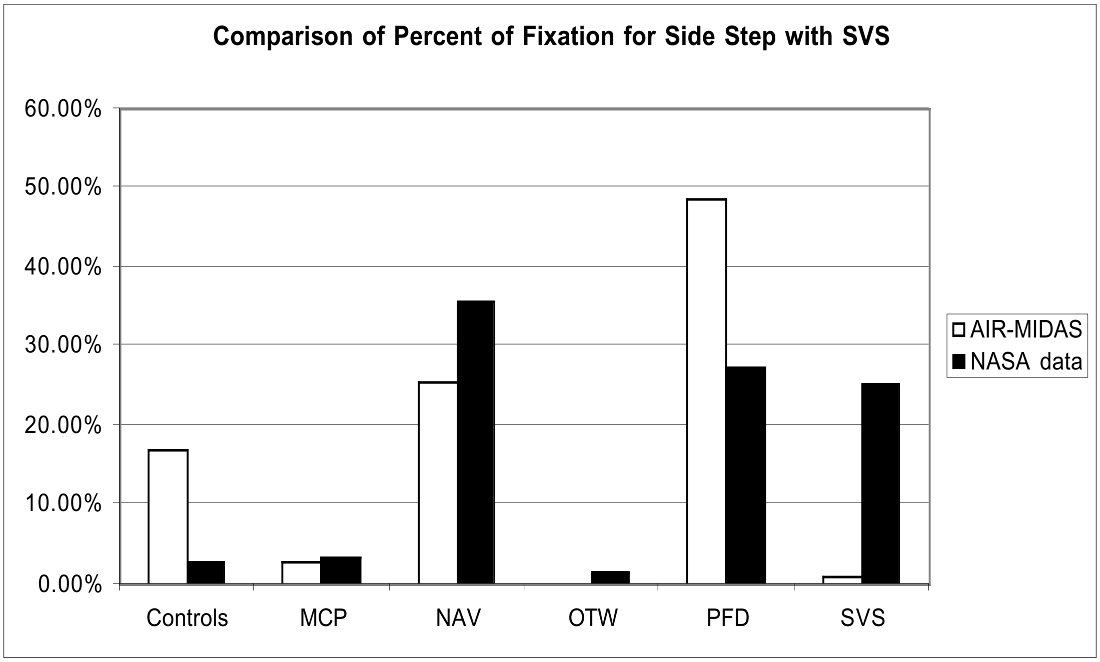

Figure 6. Model-Human Comparison of Side Step (With SVS) Fixation Percentage Location.

The correlation of dwell time performance between human and model is the least in the side step maneuver scenario. This is not unexpected as the sidestep maneuver is the furthest procedurally from the model baseline parameters. The kinds of information needed to support the side step and its implementation in SVS will need to be more closely examined in the next phase of the grant to better tune the model performance and dependence on the SVS system. In the current phase, the procedures associated with sidestep and SVS use are correlated but not highly correlated with the human performance.

Summary:

The Team HAIL data accurately produced the Mumaw, et al. (2000) scan patterns and correlated well with the NASA part-task simulation. The model behavior is roughly congruent with the human operators performance across experimental conditions with the exception in the side-step SVS condition. Team HAIL concludes the need to revisit that set of SVS side step procedures (and other detailed procedure issues not mentioned here) to tune the behaviors output by the model.

<u>Lessons Learned</u>

Air MIDAS Technical Issues

- There was a significant challenge involved in populating the Air MIDAS equipment data with aircraft state/equipment data obtained from the NASA HPM Organizing Team due to the differences in temporal resolution of data.

The simulation data was collected every 10 msec by the simulation used by the NASA HPM (2002) SVS team, whereas the tick resolution used by Air MIDAS is 100 msec. There was significant effort involved in data reduction and data management to synchronize the part task simulation data with Air MIDAS equipment data.

- The initial representation of the accuracy function was the same for both the non-directed visual sampling behavior and for directed information seeking behavior. This was changed because randomness in the model was not appropriate for some of the goal-directed information seeking the simulated agent undertook. The change in the implementation of the accuracy function was based on the presumption that goal-directed behavior will always perceive the information accurately.

- The large reduction in correlation between the NASA HPM (2002) simulation eye pattern fixation data and the Team HAIL Air MIDAS simulation eye pattern fixation data suggests that more programming is needed to augment the simulation environment in the sidestep procedures with the SVS display technologies.

Future Research Consideration for the HPM Group

Visual detection was noted as being a difficult augmentation. This difficulty was overcome by using the human performance scanning data that was provided by the HPM Organizing team and the research reports provided by the HPM Organizing Team. Of note, Team HAIL used Mumaw, et al. (2000); Micro Analysis and Design s reports to generate behavioral patterns associated with current day and future display augmentations. Visual target detection was also noted as being a difficult task to incorporate into the human performance model. Landy (2002) provided equations that enabled Team HAIL to incorporate some notion of target detection but Team HAIL did not possess the algorithms to incorporate attention-related target detection equations that could be associated with colors super-imposed on a display source (e.g. pane of glass on top of an external terrain). This augmentation would be a benefit for the modeling software.

It became apparent in working through the requirements to incorporate vision into a human performance model that representing the manner in which human beings perceive distance is a significant challenge that the current state of the art in human performance modeling has yet to address. The main reason that this has not been addressed stems from the lack of the understanding from the modeling community on methods to validly represent the human operator s perceptual characteristics with respect to depth perception and following behaviors when using automated mechanisms. There has been some progress made on theoretically implementing such a micro model in the Air MIDAS visual processing

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Attention-Situation Awareness (A-SA) Model Interim Report

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Project Report: December 30, 2002
NASA Grant # NAG 2-1535

Description of Modeling Effort

Foundation of the model. The underlying theoretical structure of the A-SA model is contained in two modules, one governing the allocation of attention to events and channels in the environment, and the second drawing an inference or understanding of the current and future state of the aircraft within that environment. The first module corresponds roughly to Endsley s (1995) Stage 1 situation awareness, the second corresponds to her Stages 2 and 3. In dynamic systems, there is a fuzzy boundary between Stage 2 (understanding) and Stage 3 (prediction) because the understanding of the present usually has direct implications for the future.

The elements underlying the attention module are contained in the **SEEV** model of attention allocation, developed by Wickens, Helleberg, Goh, Xu, and Horrey (2001), and are shown schematically in Figure 1 (McCarley, Wickens, Goh, & Horrey, 2002). These elements indicate that the allocation of attention in dynamic environments is driven by bottom up attention capture of **salient** events, is inhibited by the **effort** required to move attention (as well as imposed by concurrent cognitive activity), and is also driven by the **expectancy** of seeing **valuable** events at certain locations in the environment. The first letter of each of the four boldfaced terms, defines the SEEV model.

In Wickens and McCarley (2001), we applied a version of this attention model, coupled with a version of an inference model based on the belief updating model of Hogarth and Einhorn (1992), to develop a version of the A-SA model that could be applied to predicting errors in taxiway navigation.

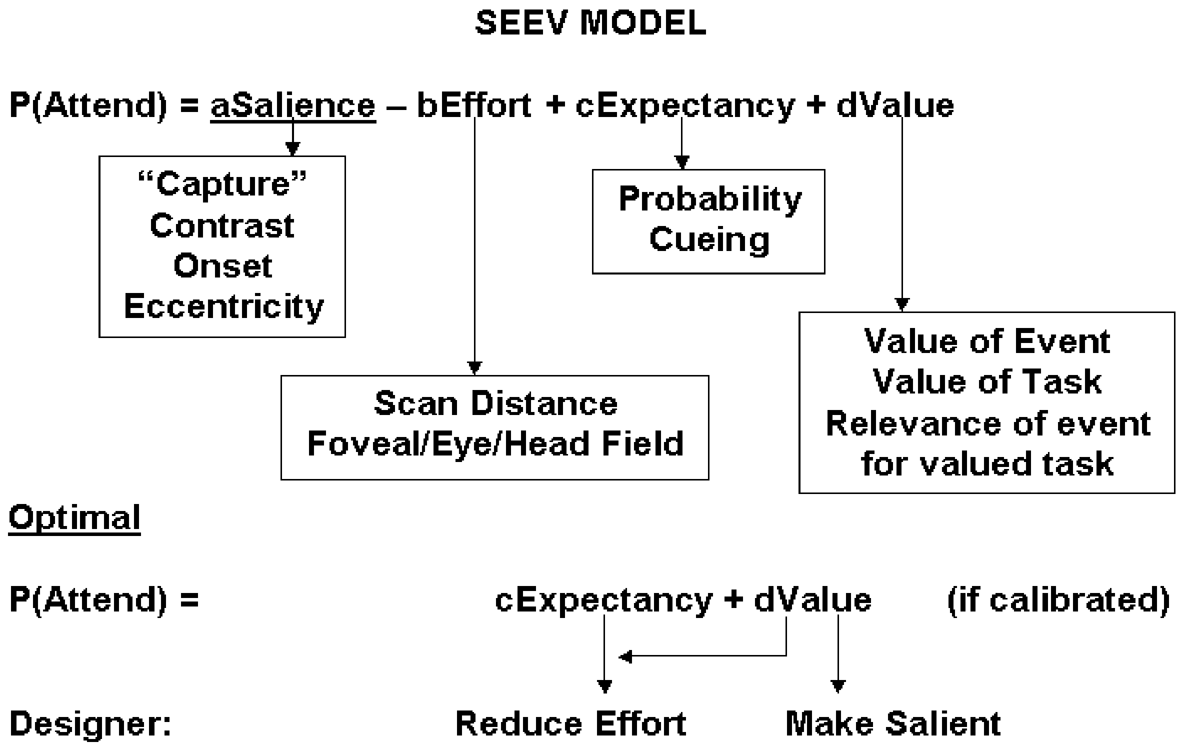

Figure 1. The SEEV model.

In the second year of the project, we have been asked to apply the model to a very different sort of data, describing pilots performing simulated approaches to an airport, when supported or not supported by a synthetic vision system (SVS) display, intended by designers to support situation awareness. Several things about this new validation effort required us to modify our modeling approach from that used in the first year. First, loss-of-SA incidents were now quite scarce in the data provided by NASA. Second, we did not have available any explicit or implicit probes of SA (e.g., SAGAT) that might also have availed data for modeling. Third, although we were provided with a full set of data records in both video and digital files, these revealed few discrete events that could be tied to the gain or loss of SA, in the same manner that the events from the taxiway data had been able to do. With fewer events it became more difficult to employ the salience component of the SEEV model, since salience serves the model only to the extent that it can be defined as a direct property of a discrete event.

To compensate for these shortcomings of the current data set, we were provided an extensive set of eye-movement data, which, in contrast to the first year taxi-data, we could now model directly as the output of our attention module. In addition, while we did not have events defined by salience, we **did** now have available channels defined by distinct locations. Following the precedence of our previous scanning model approaches, we define these channels as **Areas of Interest (AOI)**. Each AOI can be defined in terms of a (1) **transition to it**, or **visit** (from another AOI), a (2) **dwell duration** on the AOI before leaving it, and a (3) **percentage dwell time** looking at it (which is the product of the frequency of visits and the mean dwell duration, divided by the total amount of time). While we could not thereby model the salience of events, we were able to model the **effort** of moving attention (transitioning) from one AOI to another, assuming that such effort is monotonically related to the distance between AOIs. Furthermore, since the approach/landing task is one that has been often studied within the aviation domain, we were able to define the **value** of tasks on the well established hierarchy of **aviate > navigate**. Following the procedures developed in Wickens, Helleberg, Goh, Xu, and Horrey (2001), we modeled the value of an AOI to be the value of the task served by the AOI multiplied by the relevance of that AOI to the task in question. Finally, also following similar procedures to those used in Wickens et al. (2001), we modeled the **expectancy** for information contained in an AOI, in terms of the **bandwidth** of information in that AOI (that is, the frequency with which events or changes occurred to information contained within the AOI).

General approach to modeling. Figure 2 provides our schematic representation of the approach to the landing used in the current SVS simulation. Importantly, each approach in the 10 scenarios that were described by NASA can be subdivided into four phases, distinguished from each other by potential changes in relevance and bandwidth (in some scenarios):

- Ph 1. Above 1000 ft. Regular steady state flight.
- Ph 2. 1000 ft — 850 feet. Lined up on runway (whether visible or not).
- Ph 3. 850-600 feet. Runway becomes visible in most VMC landings.
- Ph 4. Below 600 feet. Runway remains hidden in low-visibility go-around scenarios.

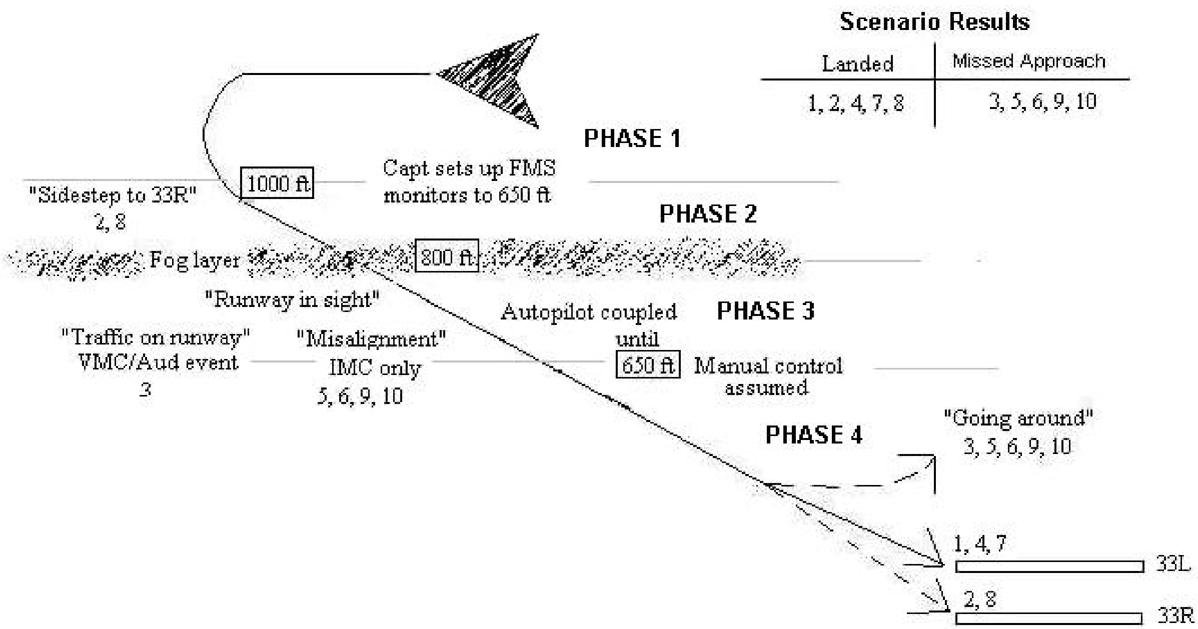

Figure 2

Each of these phases defines a separate eye-movement data base to be analyzed. With this representation of the data, we chose to model two landing scenarios provided by NASA: Scenario 6, a baseline scenario flown in IMC, in which a mismatch between the visible runway and the ILS instrument forced a go-around below 850 feet, and Scenario 10, in which the same mismatch was reflected in a misalignment between the SVS display, and the runway view.

The quality of situation awareness was operationally defined by the speed with which pilots became aware of the misalignment in the two scenarios. Careful review of the video tapes and transcriptions revealed that in both scenarios, pilot 5 maintained good SA, rapidly noticing the misalignment and executing the missed approach, whereas pilots 3 and 4 either noticed this after a considerable delay, or not at all, needing to be reminded by the confederate first officer. The distinction between the two classes of pilot behavior (good and bad SA) was important, allowing us to discriminate their attention allocation behavior, as we describe below.

We then implemented the model to predict scanning data within the 4 phases of these two scenarios in two ways, both with and without the effort coefficient included. We also used these two different models to predict two different aspects of the visual scanning data: frequency of the actual transitions between AOIs, and the mean dwell durations upon each AOI. We made such predictions for each individual pilot, and correlated predicted versus obtained scanning data, thereby using the product moment correlation as a measure of model fit. We examined correlations of individual pilots, and the correlation with the average scan data across all pilots.

Findings

Generally, the correlations ranged between 0.50 and 0.92. Our findings revealed that correlations were generally higher without the effort parameter, suggesting that these pilots did not allow the greater effort of longer scans to inhibit their search for valuable information. In general the model fit was better for scenario 6 (without SVS) than for scenario 10 (with SVS), and the lower correlations in the latter case, resulted from model prediction of more scanning to the SVS than the pilots actually showed. There was some evidence, across both scenarios, that the high SA pilot (#5) showed a better model fit, than did the two low SA pilots (3 and 4). Further analysis of scan patterns revealed qualitative differences related to transitions and dwell duration to which the model was not sensitive. In particular, the high SA pilot made direct transitions between the instrument (panel, or SVS) and the outside world for which a comparison was necessary to detect the misalignment, and this transition involved a long fixation on the latter AOI. Further details of these analyses can be found in Wickens McCarley and Thomas (in preparation).

Implications

One major implication appears to be that, in the environment modeled here, the effort of making longer scans does not appear to inhibit those scans. That is, the model fit is just as good, when driven by only bandwidth and relevance, as when effort is included. Such a conclusion is consistent with our findings in previous research (Wickens et al, 2001), that scanning of instrument rated general aviation pilots can be very effectively modeled with only expectancy and value as parameters.

A second implication is inherent in the better model fit of the good than the bad SA pilot(s), a discrimination that provides some validation of the model.

A third implication is that the wide individual differences that appear to exist within the data provided, may be modeled as much by the dwell duration, as by the particular transition. Such a distinction is one drawn by Harris and Christhilf (1980), and Bellenkes Wickens and Kramer (1997) between short dwells, designed to confirm hypotheses, and longer dwells, designed to new visual information. However the dividing line between these two forms of dwells here (around 2 seconds) is generally longer than that observed by Bellenkes et al and by Harris and Christhilf (around 1 second) This discrepancy can in part, be accounted for by the fact that those investigators did not examine scanning in off-normal scenarios.

A fourth implication may relate to the difference between model generated scanning and pilot scanning in scenario 10 phase 1, which is steady state scanning with an SVS display. Pilots appear to use this display less than the optimal model parameters suggest that they should, relying instead more on the NAV display. Such a difference may reflect the pilot s tendency to trust the more familiar display, and may suggest the importance of incorporating more navigational information into the SVS display.

Lesson Learned

In terms of our modeling effort, we are learning the importance of incorporating dwell duration into our modeling effort. Our current work with the model is undertaking this objective for the current data.

We believe that our particular modeling effort suffered from the paucity of direct situation awareness measures available in the current simulation, and hence a lesson learned might be the need to lobby for more explicit SA measures collected in future scenarios. That is, as noted, our primary focus has been on modeling Stage 1 SA (Attention and noticing events, inferred from scanning), rather than the objective of Stage 1 SA, inherent in Stages 2 and 3 (understanding and prediction). We were not able to firmly link the former to the latter, because of the paucity of data that could be used to infer the presence or absence of Stages 2 and 3 SA. Correspondingly a more robust test of the model can be achieved with data from a greater number of pilots. This would provide a wider range of responses to off-normal events, a criterion that could be used for model validation. In this context we did feel fortunate that the pronounced differences between the two classes of pilots (5 vs. 3&4) emerged.

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Modeling the Baseline and SVS-Equipped SBA Approach and Landing Scenarios

Stephen Deutsch and Richard Pew

BBN Technologies

Project Report: December 2002
NASA Contract Task Order 18

Description of Modeling Effort

As we shifted our focus to the Synthetic Vision System (SVS) equipped flight deck, the basic idea behind last year s investigation of human error in aircrew procedures continues to be the driving force for this year s modeling effort: human error can be discovered in thoughtful, detailed models of robust, successful human performance. Key elements of the scenarios have changed: the aircraft is landing at Santa Barbara Municipal Airport (SBA), rather than at O Hare, the approach is an RNAV approach rather than an ILS approach, and most importantly, the baseline flight deck has been supplemented by an SVS in four of the ten NASA scenario trials for which we have human subject data. Our long-term goal is to explore the mitigation of error routed in accident precursors: basic questions include, how does the addition of an SVS contribute to the mitigation of error and, how might we mitigate new sources of error as an SVS system is employed. The present effort has focused on building robust models of aircrew procedures for the RNAV approach and landing at SBA using the baseline and the SVS-equipped flight deck.

NASA Ames made available important resources to support the new modeling effort. A cognitive task analysis (Keller & Leiden, 2002a) provided a detailed description of aircrew and air traffic controller procedures for an RNAV approach. The document also included information on flight deck systems that support an RNAV approach. An addendum to the document (Keller & Leiden, 2002b) extended the task analysis to include the aircrew s use of an SVS during the approach and landing. In addition, we participated and profited from an SVS/SWAP information-sharing workshop held at NASA Langley late in 2001.

Our modeling effort relied heavily on the documentation of the baseline and SVS part-task scenario trials. NASA (2002) provided a detailed description of the simulated flight deck, the design for the ten scenario trials, a description of the scenario trial data for the three subjects that included simulation output, eye tracker data, and video (and audio) recordings based on an eye-tracker camera and a room-view camera. These data provided detailed insight into aircrew behaviors essential to modeling the baseline and SVS-assisted approach and landing trials.

Five SBA scenarios were addressed in the present modeling effort: the baseline nominal visual meteorological condition (VMC) and instrument meteorological condition (IMC) approaches, the SVS-equipped nominal IMC approach, and baseline and SVS-equipped approaches that included a late reassignment to a parallel runway. In the scenarios modeled, each aircraft is populated by cognitive models for the captain and first officer. The aircrew models are extensions of last year s models that executed the O Hare ILS approach, landing, and taxi. The RNAV procedures that they employ at SBA are based on the Keller and Leiden (2002a) cognitive task analysis. Consistent with our goal of examining error mitigation for two person crews, our models closely follow the Keller and Leiden task analysis rather than the exact procedures as tailored for the part-task simulation trials. In the same spirit, the approach and landing follows the standard progression from approach controller to tower controller to ground controller terminating as the aircraft completes the landing and taxies to the concourse. For the late reassignment scenarios, the subject aircrew trails a lead aircraft that blows a tire on landing and temporarily holds on the active runway creating the situation that forces the runway reassignment.

The aircraft model includes the instruments and controls necessary for the crew to execute the required approach and landing scenarios. The principal instruments include the primary flight display (PFD), the horizontal situation indicator (HSI), and the SVS. Controls include switches for the autopilot, a mode control panel (MCP), throttles, and flap and landing gear levers. The aircrew makes use of the approach plate for SBA runway 33L for information on the RNAV approach. Voice communication by the captain and first officer is used to coordinate the execution of approach and landing procedures. Party-line radio communication is modeled with the aircrew resetting radio frequencies as they move from one controller to the next.

Using information from the approach controller and the approach plate for SBA runway 33 left, the captain starts the scenario by reviewing this information with the first officer. They then focus on navigation as the aircraft proceeds from one fix to the next. As they approach each fix, they set the altitude for the next fix and monitor the aircraft s heading and altitude change (information derived principally from the HSI) as the aircraft transitions toward the next fix. During the approach, the captain calls for speed and flap settings and checklist execution. The first officer calls out the altitude at 1000 feet, as they approach decision height, and at 100 feet. The captain is responsible for the out-the-window sighting of the runway and making the decision to land. For the SVS-equipped, IMC-condition scenario, the captain can use the SVS to acquire the runway before they break out of the cloud cover, but must still acquire the runway out-the-window to make the decision to land. The captain must take manual control of the aircraft to preempt the preprogrammed go-around and manage the landing.

Figure 4 provides a plan view of two aircraft on their approach to SBA 33L. The first aircraft will blow a tire on landing causing it to hold temporarily on the active runway making it necessary for the tower controller to ask the second aircraft to side step to runway 33R. The panels on the right record details of the conversation on the flight deck of NASA186 and between the controllers and the two aircraft on the approach.

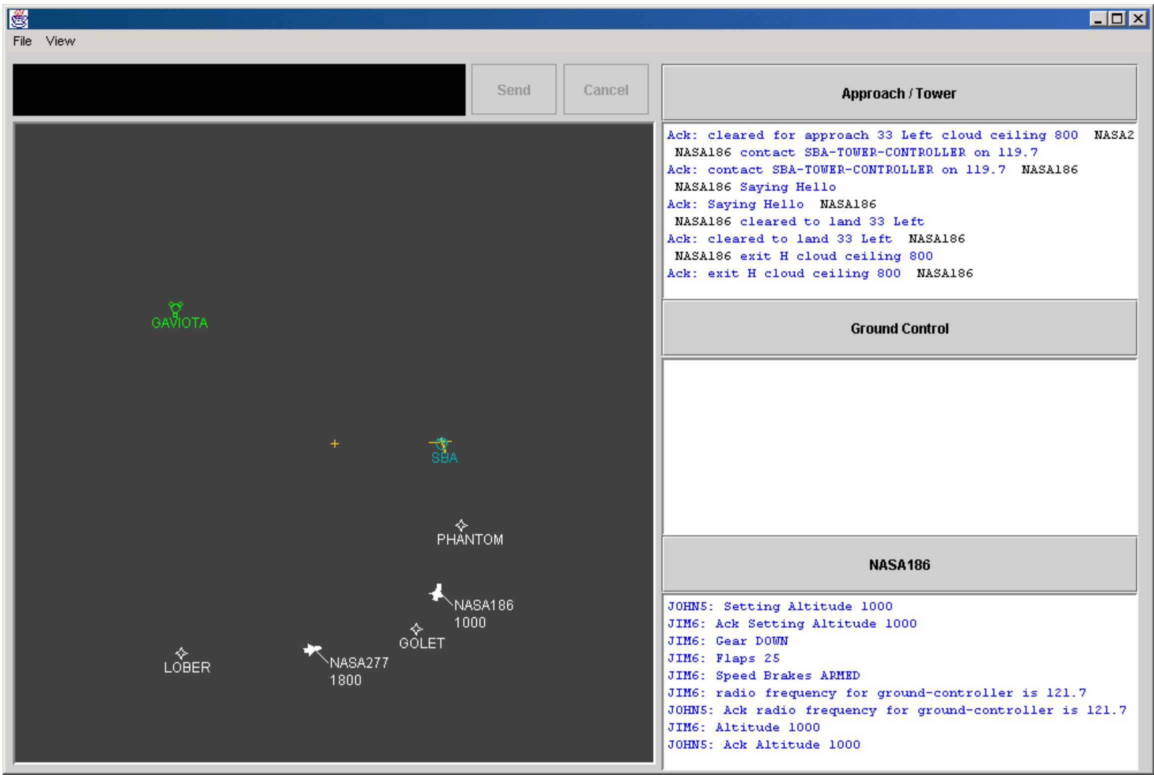

Figure 4 Screen view from the side step scenario

D-OMAR simulation tools provide explicit measures of model behaviors. A Gantt chart display provides detailed information on goals and procedures as executed by the captain and first officer. An event timeline provides detailed insight into the behaviors of the publish-subscribe protocol used to coordinate procedure execution. A plan view (Figure 4) allows an observer to monitor the progress of the aircraft along its flight path. The plan view display has recently been supplemented by a similar HSI-like display. Lastly, a detailed event trace is recorded for each simulation run with key events displayed on the screen as the simulation progresses.

Findings

The D-OMAR aircrews readily accomplished the five modeled scenarios. For the baseline scenarios in VMC and IMC conditions, the modeled aircrews successfully executed the approach and landing using RNAV procedures much as the human subjects did in the part-task simulation. The story was much the same for the nominal approach in IMC conditions using the SVS-equipped flight deck. When on the baseline VMC approach and the SVS-equipped IMC approach, the tower controller requested that the aircrew side step from SBA runway 33L to the closely parallel runway 33R, the aircrews accepted the request and successfully executed the side step to runway 33R.

Actual performance of the aircrews can be followed at several levels of detail either during scenario execution or by reviewing data collected during a simulation run. A time-tagged on-line trace tracks the aircrew s conversation on the flight deck as well as the exchanges with the controllers managing the airspace. The trace also tracks flight deck actions taken by the aircrew that follow from this discourse. These traces confirm that aircrew performance followed the procedures laid out in the Keller and Leiden (2002a) cognitive task analysis. A more detailed view of aircrew performance is available from the Gantt style display of goal and procedure execution. This display was used to review and evaluate aircrew performance at the level of individual procedure execution.

The addition of the SVS display to the flight deck augments the out-the-window view while at the same time providing much of the same functionality as the PFD. In our model, the captain uses the SVS to view runway 33L while still in the cloud cover, but reverts to the out-the-window view once the runway comes in sight. Interestingly, there were individual differences in the behaviors of the three subjects in the part-task experiment during the flight phase from decision height to landing. While subjects four and five made the expected use of the out-the-window view, subject three relied more heavily on the SVS using the out-the-window view for only five percent of the flight phase.

When the SVS was added to flight deck, the captain, as modeled, included both the SVS and PFD in the scan for aircraft attitude, speed, and altitude information. One impact of the scan of the two flight deck instruments with an overlap in functionality was that less time devoted to the HSI display and the navigation function that it supports. This effect was also seen with human subjects in the part-task simulation data. This observation is revisited below.

Implications

For the five SBA scenarios executed by the D-OMAR aircrew models, the aircrews readily accomplished the approach and landings using the baseline and SVS-equipped flight decks. As noted above, the modeled aircrews and the subjects in the part-task experiments tended to spend less time attending to the HSI display when the SVS was available even in the early phases of the approach where they were principally monitoring their progress along the flight path. A simple explanation might be that the aircrews had sufficient time to accomplish their navigation task and were simply using the HSI as required.

On the SVS-equipped flight deck, the aircrews effectively had two attitude displays and in scanning the two separate instruments, they may have been drawn to spend more time attending to attitude-related information than was necessary when using a single display configuration. In situations where time pressure is high, having two instruments from which to obtain required information can impose the additional burden of changing a habituated two-instrument scan pattern when change is most difficult. If feasible, an SVS that has nominal PFD behavior as a fail-safe mode might be considered and explored as the single attitude instrument.

Lessons Learned

The aircrew models that executed the ILS landings at O Hare for last year s study proved to be readily extendable. The RNAV approach, as detailed in the cognitive task analysis (Keller & Leiden, 2002a), required the implementation of broad range of new goals and procedures, but it was relatively easy to accomplish that within the framework for the cognitive models established for the O Hare scenarios. Constructing the SBA airport model was done using data structures developed for the O Hare model. The availability of an airport physical description database would certainly help this process. D-OMAR provided good support for developing the SBA scenarios developed to date.

The part-task simulation data has proven to be a very valuable resource with much still to be learned. In particular, the fixation sequence data files and the eye tracker video tape provide a level of detail in instrument scanning that our models ought to more accurately represent. For the present, the models look at an instrument and read the instrument s data items in a single pass. The eye tracker fixation data videotapes suggest that the pilots selectively and repeatedly scan individual items within a display before moving on to the next display. Our models will better represent pilot performance to the extent that this behavior is better understood.

Our long-term goal remains to make use of the understanding of pilot behaviors as represented in human performance models to explore the means to reduce accidents by mitigating system-wide accident precursors. Aircrews, the pilots in the part-task experiments and the D-OMAR pilot models in the SBA scenarios, readily make appropriate use of the SVS. The scenarios as modeled, add complexity to the scenarios as executed in the part-task scenarios. We would like to build further complexity into the scenarios, refine crew procedures for the use of the SVS (possibly eliminating the PFD for some scenarios), and run a series of trials with the aim of probing modeled pilot behaviors for potential benefits as well as errors that might occur on the SVS-equipped flight deck. For human performance shortfalls that lead to errors, we would like to examine approaches to mitigate those errors.

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Modeling of Pilot Tasks in the Approach and Landing Phase of Flight using IMPRINT and ACT-R

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Micro Analysis and Design, Inc. and Carnegie Mellon University

Description of Modeling Effort

The approach that was used by the Micro Analysis and Design (MA&D) and Carnegie Mellon University (CMU) team to perform the Approach and Landing modeling task is an integration of the Improved Performance Research Integration Tool (IMPRINT) and the Atomic Components of Thought — Rational (ACT-R) cognitive modeling tool. It was agreed at the last Human Performance Modeling (HPM) workshop that the scenario for all of the modeling teams would be a late reassignment of runways. There have been several sources of data for the modeling effort. The primary data source was a Cognitive Task Analysis (CTA) that was conducted as a separate effort in support of all of the modeling teams. The CTA was supplemented by a number of published papers and other background documents. In addition, videotapes of pilots flying approach and landing tasks in a NASA part-task simulator were provided. Following is a brief description of each modeling tool and what each provides for the integration.

The results of the first year of the NASA HPM project from MA&D is a simulation model of an aircraft making its final approach and landing into an airport. The specific scenario that was chosen for this first effort was of an approach with a late reassignment. The simulation model was built using the IMPRINT simulation tool. The model built specifically represents an aircraft and its environment. Currently this environment includes the altitude at which the ground and runway can be seen from out the window and the air traffic control communications. The model has been designed for more environment variables to be added as required. For the simulation of the aircraft, Imprint represents the autopilot as well as the physics of the aircraft. These aspects include the aircraft s location in time and space, its deceleration, descent ion, and all physical changes in the aircraft including its landing gear, flap settings and air brakes. The model also includes the controls and displays of the aircraft including all autopilot functions. Represented in the model are the mode control panels, the primary flight display, the navigational display, and an out the window view. The model also handles all communication between the aircraft and air traffic control. With these controls and displays, the model is able to simulate how a plane will react in its environment when these controls and displays are manipulated. Currently the simulation is setup to work with a VNAV Path autopilot setting as required for this first effort, but the model is capable of utilizing the other types of autopilot (e.g.

Glideslope and Localizer) for future analysis. In order to perform successful analyses, this model requires an outside data source to act as the pilot (i.e. human in the loop or cognitive modeling software). This data source will then issue look and manipulate commands to the controls and displays of the model as required to perform the approach and landing duties. The simulation model will terminate when the pilot switches off the autopilot for the manual portion of the landing.

In this simulation a model of the pilot was developed using the ACT-R cognitive architecture. Following the practice of decomposing complex behavior into a set of unit tasks, the ACT-R model is composed of a set of goals, together with the procedural and declarative knowledge necessary to solve those goals. The top-level goal is essentially a monitoring loop that repeatedly sets subgoals to check the settings of the various controls. Each of these subgoals typically requires acquiring the value of one or more environmental values (e.g. speed, altitude, etc) by reading the instruments or looking out the window. A decision is then made as to what the desired control value is given those readings. If that value is different from the current control, the appropriate action is performed to change that value. Decisions are made using either declarative or procedural means. For procedural control, a production rule is applied that supplies the control value given the environmental readings. This type of decision best captures crisp, symbolic decisions relying on precise values provided by instruments (e.g. set flaps to 15 when speed is 200 knots). For declarative control, instances are defined in declarative memory linking environmental readings to control values. Given a particular condition, the most relevant instance is retrieved from memory using a similarity-based partial matching mechanism, and the control value extracted from it. Multiple memory instances can also be retrieved using a mechanism called blending and a consensus control value extracted that best satisfy the set of instances. This control is similar to that provided by neural networks and best describes approximate, iterative adjustments as practiced in out-the-window flying.

Findings

The model has many potential parameters, but we can aggregate them into four main ones, represented in table 1. The first three are latencies (in seconds) which represent the time for the pilot(s) to perform perceptual, motor and auditory actions. The fourth is Act-R’s Activation Noise value, which is a measure of the stochasticity of the model s decision-making (see "The Atomic Components of Thought" for details). The first parameter is "Look", which represents the mean time for the pilot to look at an instrument and perceives its value. The next is "Action , which is the mean time it takes to perform an action such as dialing in a new setting. The last is "Listen , which represents the time that the pilot spends listening to communication before replying. These three parameters are scaling factors that vary depending on the precise perceptual, motor, or comunication act. These values specify a random distribution to represent adequate between- and within-subjects variability.

To test the model s sensitivity to these parameters, the values of these parameters were varied over a range of possible quantities. Since all four parameters had similar values we used the same test range for each parameter. Table 1 represents 100 executions of the model for each of the parameters described above. The data has the range as the columns headings and the parameters as the row heading. The values are the percentage of successful landings made in the 100 trials. Data for the default parameter values are the cells in bold-italics.

	0	**0.1**	**0.25**	**0.5**	**1**	**2.5**	**5**	**10**
Look	100	100	100	100	***90***	65	0	0
Action	100	100	100	100	100	***80***	0	0
Listen	100	100	95	***95***	50	0	0	0
Act Noise	85	***95***	60	30	20	0	0	

Table 1: Percentage of correct landing as a function of parameter values.

Implications

The execution data show that the model is quite sensitive to the time parameters. The default values tend to be at or near the break point with respect to performing successfully. For example, the default for the Look parameter is 1. At this delay, it produces 90 out of 100 landings as successful. However, when the time for the look parameter is increased, performance quickly and catastrophically declines. On the other hand, if that time is decreased performance becomes flawless. The same is true for the other parameters. We would like to rerun the model with a finer scale of time parameters.

At this point, running the model with the model with and without synthetic vision technology will produce very similar results since both conditions produce clear daytime vision of the terrain and runway, with the important difference that the average perceptual time is significantly reduced, on the order of a Look parameter value of about 0.5, primarily because shifts of attention are greatly reduced because of the integrated display. This puts SVS operation in the range of safe, successful performance rather than the break point pictured above for conventional systems. We still need to more finely model additional savings achieved from the heads-up SvS display.

Lesson Learned

Our main advance in performance modeling consists in linking a discrete-event simulation tool such as IMPRINT to a cognitive architecture such as ACT-R. This combination works quite well in alleviating the shortcomings of each platform: the cognitive architecture provides a higher-fidelity representation of human performance than task network models, and the discrete-event simulation provides a transparent, scalable representation of the world to interact with the human performance models.

We learned that, in order to accurately model the behavior of the pilot and to be able to predict errors that he will make, we need as much specific information as possible, especially in terms of the response of the aircraft to various commands. Ideally, we would like to hook our ACT-R model directly to the NASA part task simulator. In this way we could ensure that we present the model with the full rigor of the task and replicate exactly what the pilots did in the experiment.

Summary Report in Support of Milestone 2.2.1/ 7

Human Performance Modeling Element

Appendix B:

HPM -SVS Part-Task Simulation Report: Characterizing Pilot Performance During Approach and Landing With and Without Visual Aiding

June 21, 2002
Prepared by the Human Performance Modeling Element of the System-Wide Accident Prevention Project of the Aviation Safety Program

PURPOSE

The purpose of this report is to document the specifics of the recently completed part-task simulation and to help clarify the output data for analysis and interpretation. The simulation was conducted in order to collect nominal data which would characterize pilot performance during the approach and landing phase of flight using conventional and augmented displays under both Instrument Meteorological Conditions (IMC) and Visual Meteorological Conditions (VMC) conditions. The test plan, rather than emphasizing statistical power, focussed on a limited number of subject pilots operating across a variety of conditions from which performance estimates could be derived.

Three types of data were collected and are described in this report: (1) time-referenced digital data concerning aircraft position and state, pilot control inputs, and eye-gaze (2) video recordings from both an ambient room camera and eye-tracking camera with superimposed fixation cursor, (3) post-trial questionnaires regarding workload and situational awareness. These data are being provided to modelers for use in the development and validation of their models.

SUBJECTS

Three commercial-rated airline pilots participated in the simulation study. Two of the subject pilots currently serve as 757/767 captains while the third is a FO on 747-400. Collectively they averaged more than11 years of commercial flying experience and more than 13,000 total flight hours (see Appendix A for summary of demographic information).

SIMULATOR

Physical Layout
A part-task simulator built by Monterey Technologies, Inc. was used for the data collection phase. The PC-based simulator approximates the instruments and controls of a Boeing-757. The aircraft simulator was linked with a visual data base modeling Santa Barbara Municipal Airport (SBA) and its surrounding terrain. The simulator consists of 4 display components as shown below in the diagram in Figure 1: The out-the-window scene (OTW), a synthetic

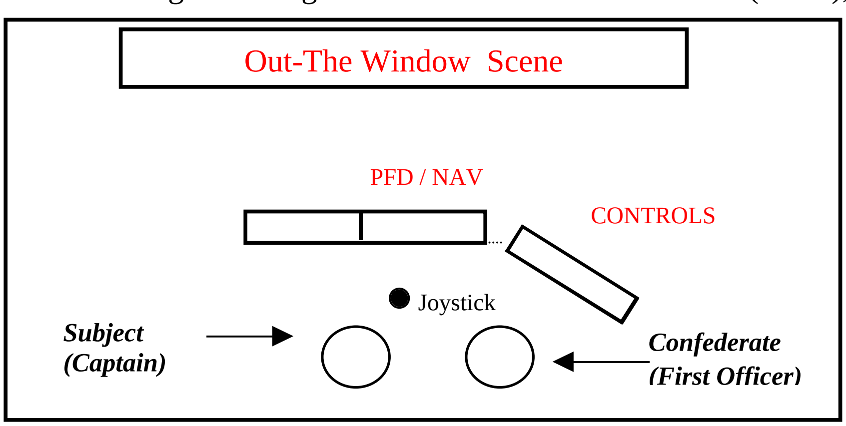


Figure 1. Diagram of physical layout of simulator components

vision system (SVS), conventional flight displays (Primary Flight Display and Navigation Display), and touchscreen software controls (MCP, Flaps, Gear, and Speed Brakes). Control inputs were made via a joystick with throttle lever, and touchscreen software buttons.

A more explicit view of the simulation is provided by two photos of the running simulation as presented in figures 2 and 3. Additionally, a set of dimensionally accurate schematic drawings is provided in Appendix B of this report so that the subtended visual angle of elements of interest to modelers can be calculated.

Figure 2. Member of the experimenter team flies a shakedown run without eye- tracking gear

Figure3. Pilot's eye perspective of simulation displays

Simulator Displays

Out the Window (OTW) Visuals: The visual out-the-world scene (shown in Figure 4) was presented in a large front projection screen measuring 96" horizontal and 71' vertical, located 93" from pilot eye point. (see Appendix B for schematic drawings). The bottom 13" of the screen was obscured at all times by the front panel of the simulated flight deck. This left a viewable region of 96" horizontal and 58" vertical which was set to a near "unity" field of view of 49.93˚ horizontal by 31.42˚ vertical.

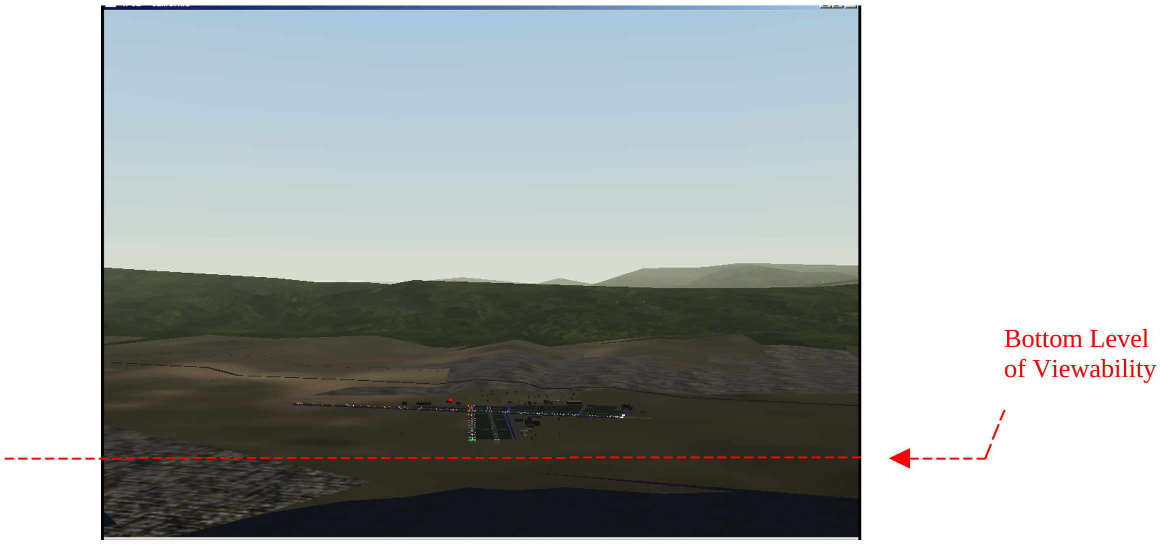


Figure 4. Out-the-World Scene approaching Runway 33L at Santa Barbara Airport in VM conditions -- dashed red arrows indicate approximate level below which screen is obscured

All simulation trials were conducted as daylight operations in either Visual Meteorological Conditions (VMC) with light haze or in Instrument Meteorological Conditions with dense fog down to 800' (or in some cases down to ground level, with 0 x 0 visibility). Presented in Figure 5 is the same Out-The-World view as Figure 4 only in dense fog during an IMC trial.

Figure 5. Out-The-World view in dense fog during IMC trial

Synthetic Vision System (SVS): The SVS was installed as a head-down display measuring 10" horizontal by 7.5" vertical (again, see Appendix B). The display presented terrain imagery overlaid with flight-director symbology. The field of view was set at 30.7˚ horizontal and 23˚ vertical which provided a "wide-angle" perspective relative to unity. An artifact of the image generation system only noticeable at altitude and only in the SVS display (fog and haze mitigating the effect in the OTW display) was the invocation of a clipping plane which painted a continuous default ground texture at viewing distances beyond 50,000 meters (approximately 30 nm). Below in figure 6 is the SVS depiction corresponding the OTW scene in figure 4. Elements of the symbology are identified in red.

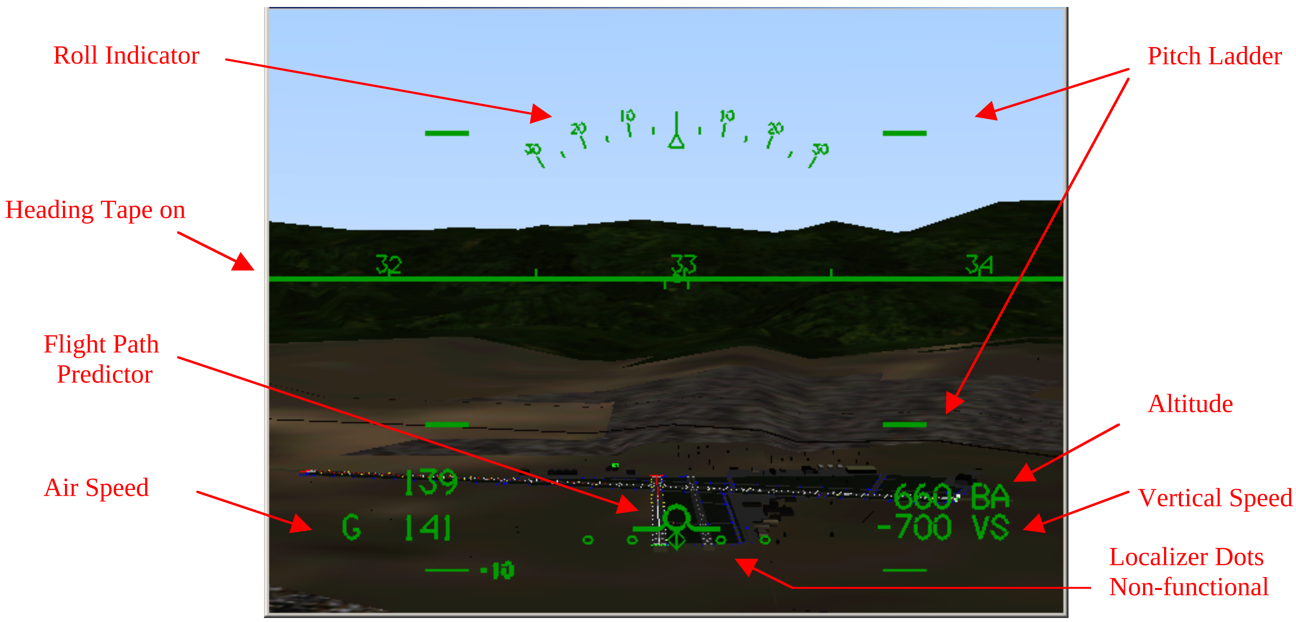


Figure 6. SVS display corresponding to the OTW scene in Figure 4 and 5 with symbology identified in red

Conventional Displays: A conventional Primary Flight Display (PFD: see figure 7) and Navigation Display (see figure 8) were presented head-down and side by side in a 5.25" by 5.25" format.

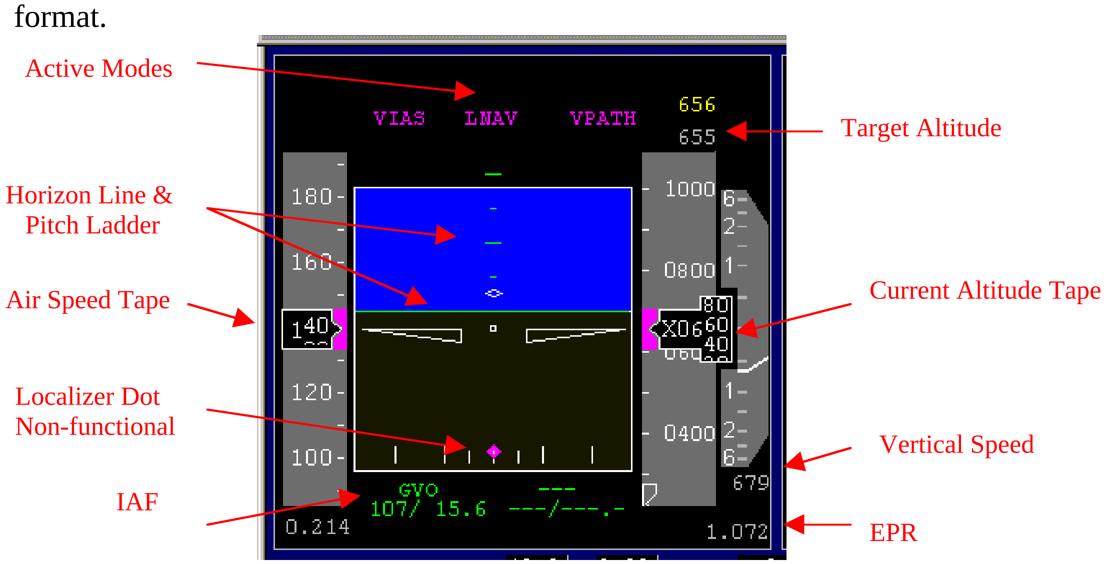


Figure 7. Primary Flight Display with symbology identified in red

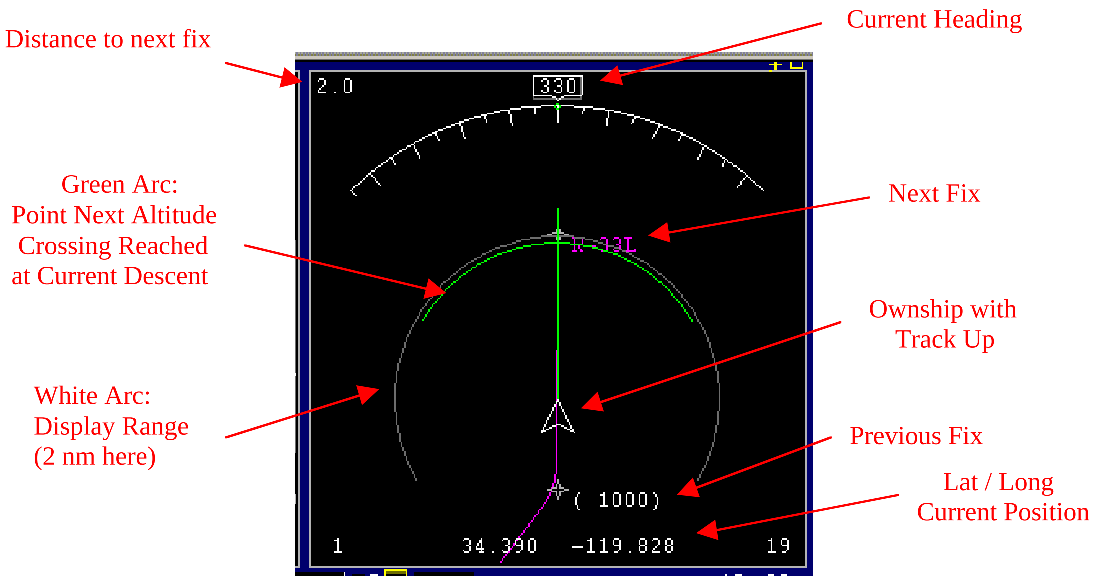


Figure 8. Nav Display with symbology identified in red

Software Controls: MCP (see Figure 9), and the gear/flap/speedbrake controls (See Figure 10) were simulated using touchscreen inputs. The confederate first officer manipulated these controls per the commands of the subject captain.

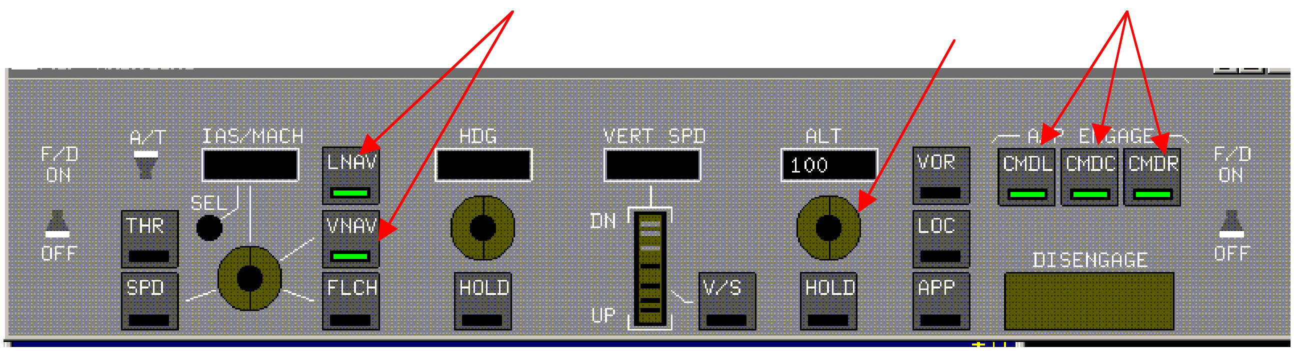


Figure 9. MCP controls presented on touchscreen display: red arrows designate the buttons and dials needed to perform the scenarios as specified for this simulation

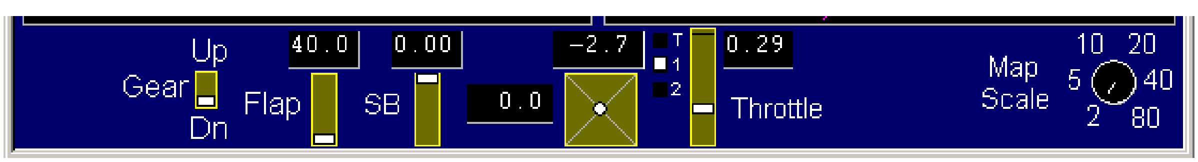


Figure 10. Gear, Flaps, and Speed Brake presented on touchscreen display

Eye Tracker:
A helmet-mounted ASL 5000 eye tracker with eye-head integration was used to collect point of gaze data from the captain. Both data stream output and a video with eye fixation overlay were recorded

Confederate First Officer:
A confederate first officer participated in the experiment to approximate realistic crew procedures and allocation of duties. (Confederate means he was a member of the experimental team acting as a First Officer). These duties included acting on all MCP and control inputs specified by captain, making appropriate call-outs, and handling ATC communications.

Confederate ATC:
An experimenter assumed the role of ATC and provided approach and landing clearances for each trial and, on occasion, a late reassignment of runway. In no instance did ATC vector aircraft off programmed route, nor was communications to other aircraft (party line communications) simulated.

BASIC SCENARIO DESCRIPTION

Approach
The simulation focussed exclusively on daylight approach and landings to Santa Barbara Airport under calm winds. For all trials, pilots performed an RNAV (GPS) approach to Runway 33L . As this approach does not actual exist, an approach plate was constructed for the simulation based on other published RNAV (GPS) plates and shown to subjects. (see Appendix C). Pilots were required to fly this approach fully coupled to the autopilot, using LNAV and VNAV down to the 650 feet decision height (DH) at which point they took manual control. Depending on circumstance, pilots either continued the landing or declared a missed-approach and executed a go-around. It should be noted that this type of approach does not require nor make use of ground-based ILS equipment (glideslope and localizer) and represents a trend in future flight operations towards aircraft-based precision guidance.

Runway 33L was selected for use for two important reasons. First, low mountain ridges ring the backside of this runway and thus create significant terrain hazards during go-around procedures. Secondly, as there exists a closely spaced parallel runway, namely 33R, the performance of a side-step maneuver on final approach could be readily investigated. However, at 4183 feet, Runway 33L is decidedly short for commercial operations. This aspect was mitigated in the minds of subject pilots as the simulation apparatus permits descent only down to 50 feet and touchdown and roll-out of aircraft were not part of simulation runs.

Initial Conditions
All trials began at 4.1 nm inbound from the Northwest to the IAF (GAVIOTA) at 10,000 feet and 250kts with a heading of 136˚. Aircraft weight was set at 200,000. The FMS was preprogrammed by the experimenter to reflect the RNAV (GPS) Runway 33L approach plate. The CDU LEGS page with its listing of fixes and associated speed and altitude restrictions (see figure 11) was shown to pilots prior to trial runs, but was not viewable during the trials.

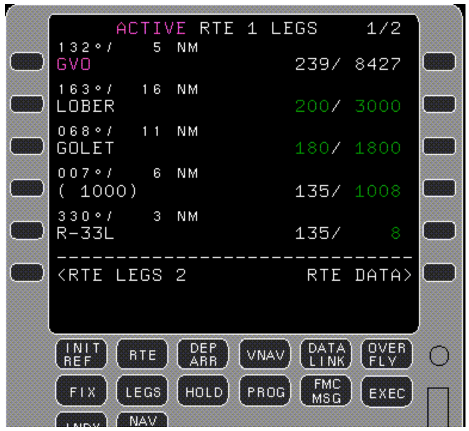


Figure 11. LEGS page as set for the RNAV (GPS) 33L Approach

Trial Termination
Depending on scenario conditions, simulation trials led to either a landing attempt or a missed-approach. For landing trials, the trial (and data collection) was terminated when the descending aircraft reached 50 feet altitude (the minimum allowed by the simulation). For missed-approach trials, termination occurred when the ascending aircraft reached 3000 feet while executing a go-around.

Pilot Instructions
Simulation procedures were reviewed with subjects during an orientation briefing . On initiation of each trial, subjects were instructed to immediately have the FO arm the autopilots (a quirk of the simulation system required all three autopilots to be set), dial down the altitude, and engage LNAV and VNAV. Thereafter, the captain's task was to monitor and supervise the programmed FMS descent and approach, commanding such actions as flaps, speedbrakes, landing gear, and altitude settings. Utilization of MCP functions such as FLCH or VS (which might disengage LNAV or VNAV) were not permitted. At DH (650 feet) subjects took full manual control (stick and throttle) of the aircraft and either attempted the landing (i.e., descent to 50 feet) or declared a missed approach and executed a go-around.

Of particular interest was the missed approach procedure which called for a climbing 180˚ left turn to 5000 feet back to GOLET . This procedure was to be performed strictly as a stick and throttle effort without benefit of a "to-go" button nor MCP interventions. Additionally, subjects were advised as to how to handle certain anomalous situations: if the FO called-out traffic, subjects were to respond accordingly without the need to visually verify; if flight deck displays appeared misaligned to the O-T-W scene, subjects were to immediately discontinue the approach regardless of their ability to correct flight path.

Subjects were asked to call-out "runway in sight" (and, <u>not</u> to ask or rely on FO to do so), "going-around" and "misalignment" (of displays with O-T-W view) and, to freely verbalize concerns or thoughts regarding the task at hand.

Prior to the start of each trial, subjects were told only whether they would be in VMC conditions (with light haze) or IMC conditions (with ceiling down to 800 feet) and whether the SVS display would be available.

TEST PLAN

Independent Variables
Three variables of interest were investigated: Display Configuration, Visibility, and Approach Event.

Display Configuration (2)
1. Baseline Configuration
This configuration represents current-day operations and consisted of the following:
- Out-the-Window display
- Conventional Display (PFD and Nav Display)
- Software Controls (MCP, gear, flaps, speedbrakes)

2. SVS Configuration
This configuration includes all displays presented in the baseline configuration with the addition of the SVS display (Terrain with flight instrumentation overlay)

Visibility (2)
1. Visual Meteorological Conditions (VMC) -- The entire trial was conducted in day visual meteorological conditions with light haze using visual flight rules

2. Instrument Meteorological Conditions (IMC) -- The trial begins in instrument meteorological conditions following instrument flight rules. Ceiling is set at 800 feet (resulting in break-out 150 feet above DH) except for the missed-approach scenario in which dense fog continues to ground creating 0 x 0 visibility

Approach Event (4):
1. Nominal Approach
ATC issues approach clearance 3 miles from IAF (GAVIOTA) and landing clearance 2.5 miles from FAF (GOLET). No other ATC communications nor unexpected events occur and a nominal landing is performed.

2. Late Runway Reassignment
Trial begins as per nominal approach scenario. At 1000 feet on final, ATC requests that crew side-step aircraft to runway 33R due to remaining traffic on 33L. With crew acceptance, ATC then clears aircraft to land 33R with nominal landing performed. Pilots had been briefed to accept and execute this maneuver even in IMC conditions (not currently allowed) using the runway visuals provided by their SVS display. This suspension of standard operating procedures did not exempt pilots from making out-the-window visual acquisition of the newly assigned runway (after breaking through the clouds) and being stabilized before passing through DH.

3. Missed Approach
Trial begins as per nominal approach scenario. In IMC conditions, the clouds do not clear, requiring the pilot to perform a go-around. In VMC conditions, the confederate first officer

announces traffic on the runway as aircraft passes 600 feet , precipitating a missed approach and go-around.

4. Terrain Mismatch
Trial begins as per nominal approach scenario. However, the instruments (PFD, NavDisplay, and SVS) are misaligned -- offset 500 feet laterally to left -- from the out-the-world view. If pilots were to follow these instruments, aircraft would touchdown 500' to the side of the runway. In essence, this is simulating an instrument failure in which the data feeding both the conventional displays and the SVS contain a 500' lateral error. The error is only noticeable to pilots upon break-out when it becomes clear that they aren’t in line with the runway as expected. Pilots were expected to call-out misalignment and initiate go-around procedures.

Design
There were10 specific combinations of variables which were investigated and designated by scenario number as shown below in Table 1. The three subject pilots were tested once across each of these10 scenarios (save for a single lost trial). Six of the scenarios were in baseline display conditions and 4 scenarios utilized the SVS display (those all being in IMC conditions). Note that the missed approach in Scenario #3 was prompted by the FO calling out

Table 1. Test Conditions

Display Configuration		Baseline	Baseline	SVS
Visibility		VMC	IMC	IMC
Approach Event	Nominal Approach (nominal landing)	*Scenario #1*	*Scenario #4*	*Scenario #7*
	Late Reassignment (side-step & land)	*Scenario #2*		*Scenario #8*
	Missed Approach (go-around)	*Scenario #3*	*Scenario #5*	*Scenario #9*
	Terrain Mismatch (go-around)		*Scenario #6*	*Scenario #10*

traffic on the runway whereas the missed approaches in Scenarios #5 and #9 were prompted by lack of visibility at DH. Also note that Scenario #8 tested pilot's ability to perform a side-step maneuver in IMC conditions using SVS visual guidance -- a potential extension of current operational procedures.

The10 scenarios were grouped into 3 testing blocks and presented to subjects as follows: first a 3-trial block of randomly selected baseline trials were flown, followed by a 4-trial block of SVS trials which were then proceeded by a 3-trial block of the remaining baseline trials.

DATA COLLECTION

Simulation Output

Digital output data were recorded at a ***nominal*** 20 Hz and included time-referenced values for aircraft position and orientation, aircraft state, and control inputs across trials. These data were merged with raw eye tracking data and converted to spreadsheet format within the files listed in Table 2.

Table 2. Listing of Data Files with Related Information

Data File Name (Subject # x Scenario #)	PcPlane Internal Clock at Start of Trial	PcPlane Internal Clock at End of Trial	Special Notes
S3Scen1.xls	1021065789.79	1021066469.41	
S3Scen2.xls	1021052513.11	1021053190.71	
S3Scen3.xls	1021070213.73	1021070947.59	
S3Scen4.xls	1021050979.37	1021051677.37	*Eye tracker data starts at 1021051066.00
S3Scen5.xls	1021053810.46	1021054535.33	
S3Scen6.xls	1021067861.36	1021068537.83	* Executed landing not Go-Around
S3Scen7.xls	1021060917.09	1021061597.11	
S3Scen8.xls	1021062005.87	1021062678.40	
S3Scen9.xls	1021059704.62	1021060443.97	
S3Scen10.xls	1021064368.55	1021065130.66	
S4Scen1.xls	1022696574.25	1022697265.69	
S4Scen2.xls	1022716487.08	1022717166.29	
S4Scen3.xls	1022704821.96	1022705571.81	
S4Scen4.xls	1022715392.20	1022716077.53	
S4Scen5.xls	1022697664.32	1022698401.01	
S4Scen6.xls	N/A	N/A	*Trial not completed
S4Scen7.xls	1022708463.73	1022709221.39	
S4Scen8.xls	1022711140.59	1022711818.51	
S4Scen9.xls	1022707150.49	1022707872.20	
S4Scen10.xls	1022712235.30	1022713009.92	
S5Scen1.xls	1022881292.24	1022881981.47	
S5Scen2.xls	1022867566.17	1022868256.00	
S5Scen3.xls	1022884021.66	1022884733.38	
S5Scen4.xls	1022866133.38	1022866827.61	
S5Scen5.xls	1022868870.43	1022869579.12	
S5Scen6.xls	1022882868.28	1022883566.86	
S5Scen7.xls	1022876204.42	1022876900.69	
S5Scen8.xls	1022878568.39	1022879254.97	
S5Scen9.xls	1022874431.63	1022875140.30	
S5Scen10.xls	1022879975.99	1022880675.54	

Collection Rate Caution

It should be noted that due to slight variations in runtime processing cycles, data was not incremented at a fixed 20 Hz rate. For this reason, caution is advised in the use of "fixed rate" analysis programs. The computer clock time (the variable "PcPlane Internal Clock") is, however, a validly incremented timestamp and can be used accordingly.

Below in Table 3 is a listing of the variables collected along with a brief description and their column location within the data files.

Table 3. Digital Variables Collected

Column	Variable	Description
A	Phase of Flight	1 = Initialization Position to IAF (GAVIOTA) 2 = IAF (GAVIOTA) to FAF (GOLET) 3 = FAF (GOLET) to DH (650 feet) 4 = DH (650 feet) to 50 feet (Landing Trial) 4 = DH (650 feet) to 3000 feet (Go-around Trial)
B	Event	Position or Fix being crossed (per above)
C	Run State	1 = Simulation running
D	Data Collection Rate	1 = 20Hz
F	Frame Count	PcPlane frame cycles at 50msc ticks
G	PcPlane Internal Clock	Continuously running computer clock in hundredth of sec
H	X Position X-IG Internal Co-ordinates	Visual data base co-ordinate system in meters
I	Y Position X-IG Internal Co-ordinates	Visual data base co-ordinate system in meters
J	Altitude	Above mean sea level in feet
K	Pitch (Degrees)	Pitch angle in degrees, positive is up
L	Bank (Degrees)	Bank angle in degrees, positive is right wing down
M	Heading (magnetic)	
O	Ground Speed (Ft/Sec)	
P	Elapsed Range from Start (nm)	Distance traveled in nm from initial start point (IP)
Q	IAS (kts)	Indicated air speed
R	True Air Speed (Ft/Sec)	** same as "O"
S	Mach	Based on airspeed and altitude
T	Vertical Speed	Feet per minute
U	True Heading	
V	Weight	Gross aircraft weight
W	Flaps (degrees)	Sim settings unconventional at 4, 15, 25, & 40
X	Throttle Setting (0 - 1.0)	Throttle position whether set manually or by autopilot
Z	Speed Brake Setting (0 - 1.0)	Proportion of extension
AA	Landing Gear	0 = stowed , 1 = fully deployed
AB	Latitude	Current position in decimal latitude
AC	Longitude	Current position in decimal longitude
AD	Joystick X (-1 thru +1)	Positive values indicate stick pulled aft
AE	Joystick Y (-1 thru +1)	Positive values indicate stick deflection to the right
AF	gamma_d	Legacy parameter of unknown type
AH	gamma_hold	Legacy parameter of unknown type
AJ	bank (radians)	Bank angle in radians , positive values are right wing down
AK	Heading Hold (degrees)	Computed target heading
AM	MCP Speed Window	TBD
AN	MCP Hdg Window	TBD
AP	MCP VS Speed Window	TBD
AQ	MCP Altitude Window	TBD
AR	Speed Mode Engaged (Light)	Speed controlled by autopilot
AS	Heading Mode Engaged (Light)	Heading controlled by autopilot

		** unreliable
AT	VS Mode Engaged (Light)	VS controlled by autopilot ** unreliable
AU	Altitude Hold Engaged (Light)	Altitude being held by autopilot ** unreliable
AV	MCP SEL Knob	SEL Knob set
AW	MCP Spd Knob	SPD Knob set
AX	MCP Hdg Knob	Hdg Knob set
AY	MCP Speed	Speed mode: 0 = off, 1 = Engaged
BA	MCP Alt Knob	Alt Knob set
BB	MCP Speed Dial	Speed Dial setting
BC	MCP Hdg Dial	Heading Dial setting
BD	MCP VS Dial	VS Dial setting
BE	MCP Alt Dial	Altitude Dial setting
BF	MCP CMDL	Left Autopilot mode: 0 = off, 1 = Engaged
BH	MCP LNAV	LNAV mode: 0 = off, 1 = Engaged
BI	MCP VNAV	VNAV mode: 0 = off, 1 = Engaged
BJ	MCP FLCH	FLCH mode : 0 = off, 1 = Engaged
BK	MCP Hdg Hold	Heading Hold mode: 0 = off, 1 = Engaged
BL	MCP V Speed	Vertical Speed mode: 0 = off, 1 = Engaged
BM	MCP Alt Hold	Altitude Hold mode: 0 = off, 1 = Engaged
BO	MCP CMDC	Center Autopilot mode: 0 = off, 1 = Engaged
BP	MCP CMDR	Right Autopilot mode: 0 = off, 1 = Engaged
BQ	Eye Track Status	128 = Active
BR	Pupil Most	Intermediate parameter -- ignore
BS	Pupil Least	Intermediate parameter -- ignore
BT	Scene Plane	Sceneplane 0 = Undefined or invalid data Sceneplane 1= Out-the-Window (OTW) View Sceneplane 2= SVS Display Sceneplane 3= Primary Flight Display Sceneplane 4= Nav Display Sceneplane 5= Mode Control Panel Sceneplane 6= Controls (Flaps, gears, speedbrakes, map scale) Sceneplane 7= Overlapping Area.
BU	POG Y Most	Intermediate parameter -- ignore
BV	POG Y Least	Intermediate parameter -- ignore
BW	POG Z Most	Intermediate parameter -- ignore
BX	POG Z Least	Intermediate parameter -- ignore
BZ	HPM Latitude Offset	SVS & NAV Display misalignment in feet (always 0)
CA	HPM Longitude Offset	SVS & NAV Display misalignment in feet (0 or -500)
CB	Pupil Size	0 = closed, if so invalidates other eye tracker variables
CC	POG Y	Horizontal offset in inches from sceneplane origin
CD	POG Z	Vertical offset in inches from sceneplane origin

EYE TRACKER DATA

General Notes:
The raw eye tracker data is provided in the simulation output file at 20 hz without any filtering or smoothing of the data. This raw data is provided so that you may perform your own processing of the data if you choose to do so. Some filtering and smoothing of the data will likely be required to make meaningful interpretations of the data. Noise in the data may be due to several sources such as blinking or a temporary loss of eye tracker calibration.

Variables:

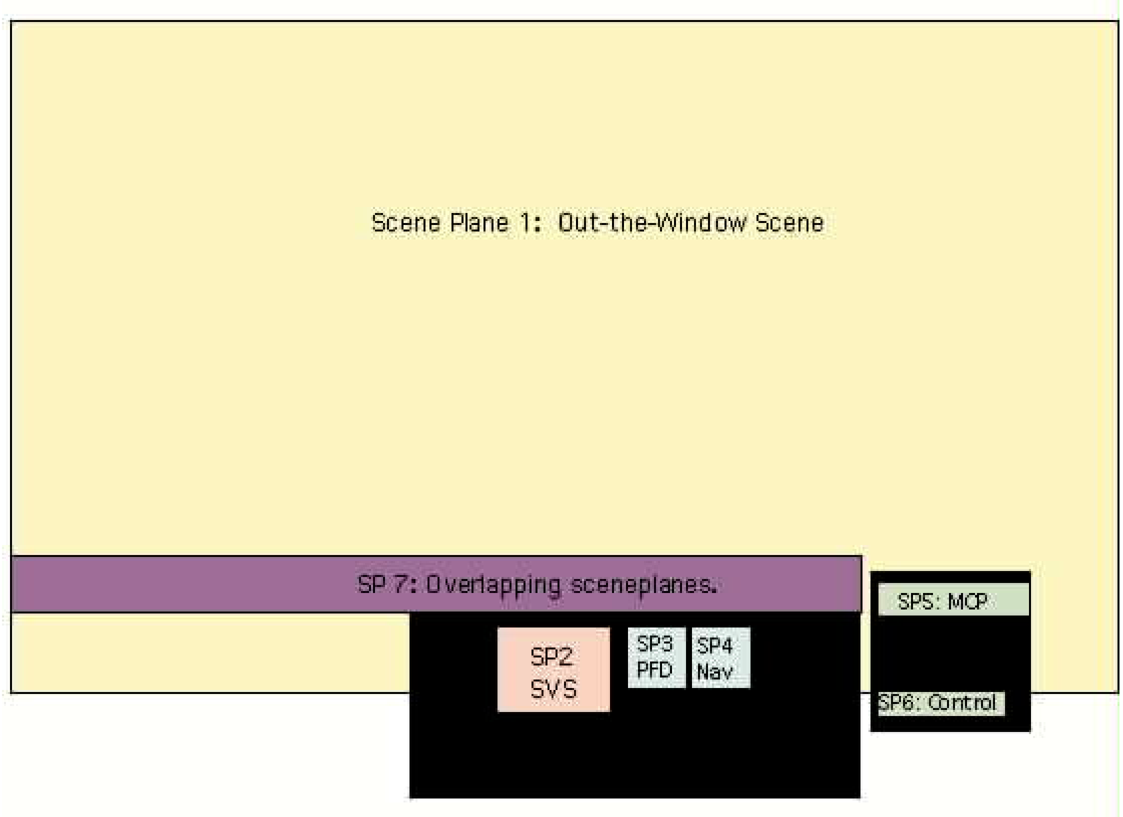
Sceneplane
Pupil Size
Point of Gaze (POG) Y
Point of Gaze (POG) Z

Other variables in the data set including POG Y most, POG Y least, POG Z most, POG Z least, pupil most, and pupil least were used to generate the final data variables listed above, but are no longer needed for analyses (you can ignore these).

Sceneplane (SP)
There are eight sceneplanes, each described below (also see schematic below)

Sceneplane 0 = Undefined or invalid data. Occurs when the eye cursor is centered on an area that is not defined as sceneplane 1 to 7 – i.e. the first officer, joy stick etc - or if the data is invalid (i.e. subject blinks).
Sceneplane 1= Out-the-Window (OTW) View
Sceneplane 2= SVS Display
Sceneplane 3= Primary Flight Display
Sceneplane 4= Nav Display
Sceneplane 5= Mode Control Panel
Sceneplane 6= Controls (Flaps, gears, speedbrakes, map scale)
Sceneplane 7= Overlapping Area. The cockpit displays sit directly in front of the lower portion of the OTW view. Depending on the viewing angle of the subject (which varied slightly by subject, and over the day of trials), the eye tracker could not always determine whether the subject was looking at the black masking area around the displays, or the OTW view behind the masking. In these cases, the sceneplane is recorded as “7”.
Given that the bottom of this sceneplane is 2 inches above the top of the SVS, PFD, and Nav display, it is doubtful that the subject was gathering data from the displays when the eye point of gaze was in this region. Further, a sub-sampling of the video tapes revealed that glances in this region are best attributed as glances to the out-the-window scene. If you intend to use these data points to determine ‘first glances’ to the OTW scene, or other similar purposes, you may find the context of the scenario, provided in the eye tracker video tape, useful to verify that glances in this region are indeed to the OTW view.

Overview of ScenePlane Layout



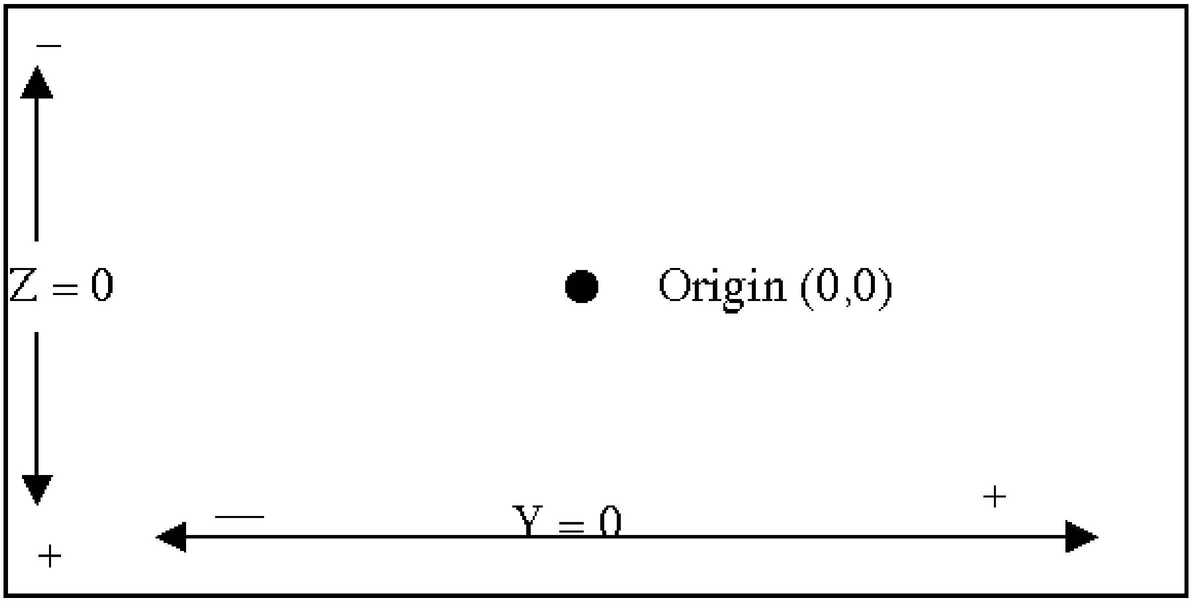
Pupil Size:
If pupil diameter = 0, the eye is closed. The data is not valid for any of the eyetracker variables (scene plane, POG Y, POG Z).

Point of Gaze (POGY and POG Z):
POG represents the Y (horizontal) and Z (vertical) coordinates in inches, relative to the origin of the sceneplane.

For each visual display (sceneplane 1,2,3,4,5,6) the origin is the exact center point of the display. Any point on the display can be characterized by their (Y,Z) coordinates. At the origin, Y = 0, and Z = 0. To the right of origin, Y values are positive and increase. To the left of origin, Y values are negative and decrease. Below the origin, Z values are positive and increase. Above the origin, Z values are negative and decrease.

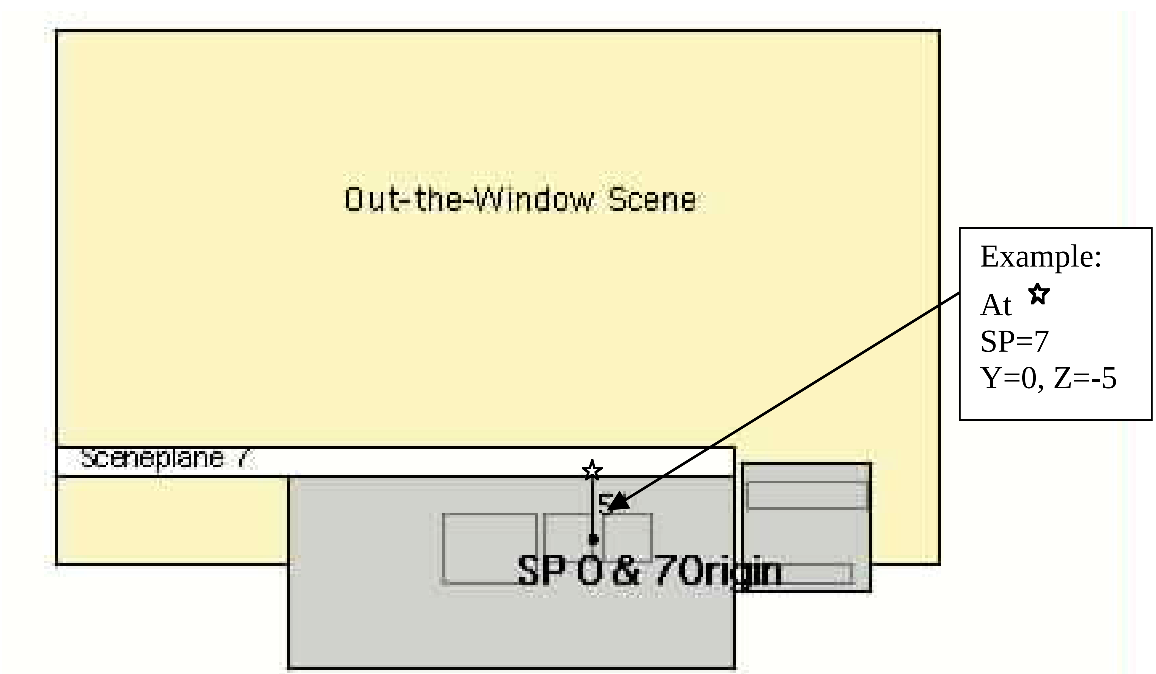
Example. A point 1" to the right of origin, and 3" above origin would have coordinates: Y=1, Z=-3.

POG Coordinates, relative to the origin of a sceneplane (visual displays)

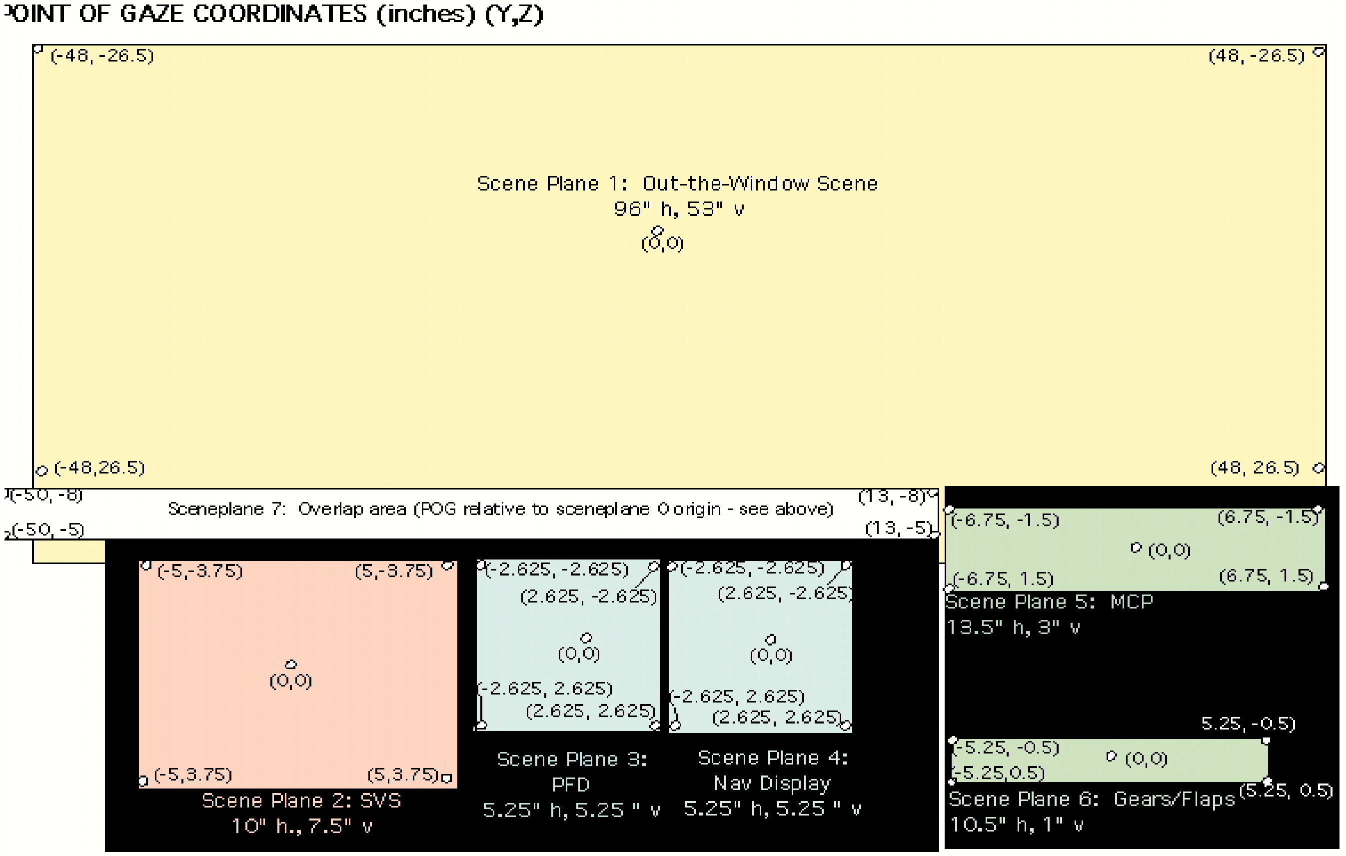


Sceneplane 0 and 7 share the same origin as shown by the black circle in the schematic below. POG Y and Z for both sceneplanes are represented in inches from this origin. For example the Y,Z coordinates for the point identified by the star in sceneplane 7 below would be sceneplane 7, (Y=0, Z=-5).

POG Coordinates. Origin Location for ScenePlane 0 and 7



The figure below illustrates the seven sceneplanes, and the POG Y and POG Z values that identify each corner of the plane.



Note: Where possible, buffers were added around edges of the displays to allow a slight margin of error (except where sceneplanes would overlap). Therefore it is possible to have POG coordinaes slightly larger than those shown above.

Audio and Video Recordings

Eye Tracker Camera

For each trial a videotape of the pilot's forward view was recorded from the head-mounted eye tracker. The pilot's point of gaze is shown by crosshairs superimposed over the visual scene. These tapes provide a fair representation of what the pilot was actually seeing at any given point in the simulation.

Room View Camera

Additionally, for each trial an ambient audio and video recording was produced that depicts displays and control inputs and verbal communications . Three audio channels were recorded as follows: left channel was the Captain (subject), right channel was the FO (experimenter), and center channel was ATC (experimenter). It should be noted that the camera was mounted high and behind the pilot and that the visual perspective in the tapes is not that of the pilot.

Annotated versions of these video recordings have been prepared for distribution to modelers and are listed below in Table 5 .

Table 5. Listing of Annotated Video Tapes

Subject #3, Tape #1

Scenario	Time-Code	Room-Camera VCR Time	Eye-Camera VCR Time
4			
start	1:48:56	0:01:15 VIDEO LOST	0:01:00
Stop	1:59:15	0:01:15 VIDEO LOST	0:11:30
2			
start	2:13:00	0:01:22 VIDEO LOST	0:11:52
Stop	2:25:33	0:01:22 VIDEO LOST	0:23:45
5			
start	2:34:37	0:01:35	0:24:12
Stop	2:47:00	0:14:00	0:36:50
9			
start	4:12:48	0:14:22	0:37:00
Stop	4:25:10	0:27:02	0:49:50
7			
start	4:33:00	0:27:25 VIDEO LOST	0:50:00
Stop	4:44:20	0:27:25 VIDEO LOST	1:01:50
8			
start	4:51:06	0:27:58	1:02:20
Stop	5:02:35	0:39:47	1:14:05

Subject #3, Tape #2

Scenario	Time-Code	Room-Camera VCR Time	Eye-Camera VCR Time
10			
start	5:30:05	0:01:07 VIDEO LOST	0:01:18
Stop	5:43:12	0:01:07 VIDEO LOST	0:14:00
1			
start	5:54:06	0:01:36 PARTIAL VIDEO LOSS	0:14:36
Stop	6:05:37	0:10:58 PARTIAL VIDEO LOSS	0:26:26
6			
start	6:28:35	0:11:20 VIDEO LOST	0:26:32
Stop	6:40:04	0:11:20 VIDEO LOST	0:38:21
3			
start	7:07:47	0:11:38 VIDEO LOST	0:38:31
Stop	7:20:05	0:11:38 VIDEO LOST	0:51:10

Subject #4, Tape #1

Scenario	Time-Code	Room-Camera VCR Time	Eye-Camera VCR Time
1			
start	1:55:35	0:01:04	0:01:07
Stop	2:07:04	0:12:56	0:13:00
5			
start	2:13:44	0:13:08	0:13:15
Stop	2:26:05	0:25:49	0:26:09
3			
start	4:12:56	0:26:04	0:26:27
Stop	2:47:00	0:38:56	0:39:00
9			
start	4:51:42	0:39:08	0:39:37
Stop	5:03:49	0:51:38	0:52:09
7			
start	5:13:33	0:51:44	0:52:26
Stop	5:25:00	1:03:30	1:04:16

Subject #4, Tape #2

Scenario	Time-Code	Room-Camera VCR Time	Eye-Camera VCR Time
8			
start	5:58:00	0:01:15	0:01:02
Stop	6:09:28	0:12:59	0:12:49
10			
start	6:16:20	0:13:12	0:13:05
Stop	6:29:24	0:26:38	0:26:28
4			
start	7:08:56	0:26:46	0:26:48
Stop	7:20:10	0:38:32	0:38:20
2			
start	7:27:09	0:38:47	0:38:36
Stop	7:38:32	0:50:37	0:50:25

Subject #5, Tape #1

Scenario	Time-Code	Room-Camera VCR Time	Eye-Camera VCR Time
4			
start	0:39:14	0:01:15	0:01:03
Stop	0:51:00	0:13:15	0:13:04
2			
start	1:03:16	0:13:30	0:13:17
Stop	1:14:51	0:25:30	0:25:32
5			
start	1:24:59	0:25:43	0:25:45
Stop	1:36:51	0:37:55	0:37:59
9			
start	4:51:42	0:38:09	0:38:10
Stop	5:03:49	0:50:20	0:50:27
7			
start	3:27:06	0:50:37	0:50:39
Stop	3:38:40	1:02:30	1:02:42

Subject #5, Tape #2

Scenario	Time-Code	Room-Camera VCR Time	Eye-Camera VCR Time
8			
start	4:06:28	0:01:15	0:00:58
Stop	4:17:57	0:13:10	0:12:53
10			
start	0:08:48	0:13:25	0:13:07
Stop	0:20:31	0:25:29	0:25:10
1			
start	0:30:42	0:25:40	0:25:19
Stop	0:42:13	0:37:29	0:37:12
6			
start	0:56:59	0:37:37	0:37:25
Stop	1:08:42	0:49:48	0:49:38
3			
start	1:16:10	0:50:04	0:49:48
Stop	1:28:05	1:02:30	1:02:08

Post-Trial Workload and SA Questionnaires

After each trial a questionnaire was given in which subjects rated on a 1 - 7 scale various aspects of their perceived workload and situational awareness across different phases of the just completed flight (see Table 4). A summary of subject responses is provided in spreadsheet format under the file name *HPM_SVS_Ratings.xls*.

Table 4. Questions and Rating Scale Used in Post-Trial Questionnaire

1. Please rate your situation awareness and workload <u>for the entire trial that you just completed.</u>
2. Please rate your situation awareness and workload for the period of time <u>from the Initial Approach Fix to the Final Approach Fix.</u>
3. Please rate your situation awareness and workload for the period of time <u>from the Final Approach Fix to the point where you took over manual control of the aircraft.</u>
4. Please rate your situation awareness and workload for the period of time <u>from when you took over manual control to the end of the trial</u>
5. Please rate your situation awareness and workload <u>associated with the task of making a visual fix on the runway.</u>

6a. Please rate your situation awareness and workload <u>associated with the task of making the decision to accept the side-step maneuver</u>

7a. Please rate your situation awareness and workload <u>during the side step maneuver maneuver.</u>

6b. If you executed a missed approach or go around during this trial, please rate your situation awareness and workload <u>associated with the task of making the decision to initiate the missed approach.</u>

7b. If you executed a missed approach or go around during this trial, please rate your situation awareness and workload <u>during the maneuver --- i.e. from the time you initiated the maneuver to the end of the trial.</u>

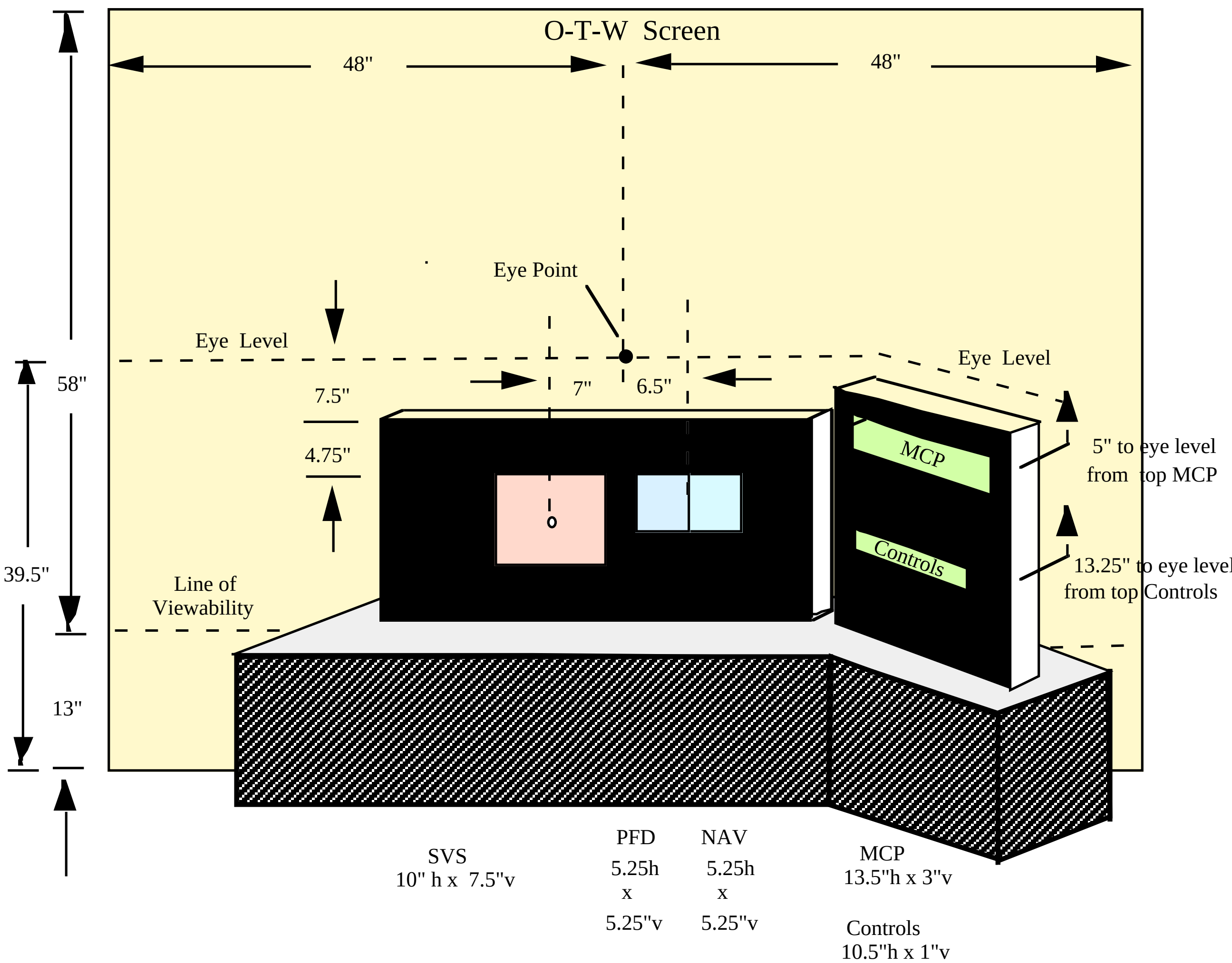
	Low			Neutral			High
Overall situation awareness	1	2	3	4	5	6	7
Awareness of terrain	1	2	3	4	5	6	7
Awareness of position relative to runway	1	2	3	4	5	6	7
Awareness of cockpit display information	1	2	3	4	5	6	7
Overall workload	1	2	3	4	5	6	7
Visual workload	1	2	3	4	5	6	7
Auditory workload	1	2	3	4	5	6	7
Cognitive workload	1	2	3	4	5	6	7
Psychomotor (physical) workload	1	2	3	4	5	6	7

Summary of Demographic Information

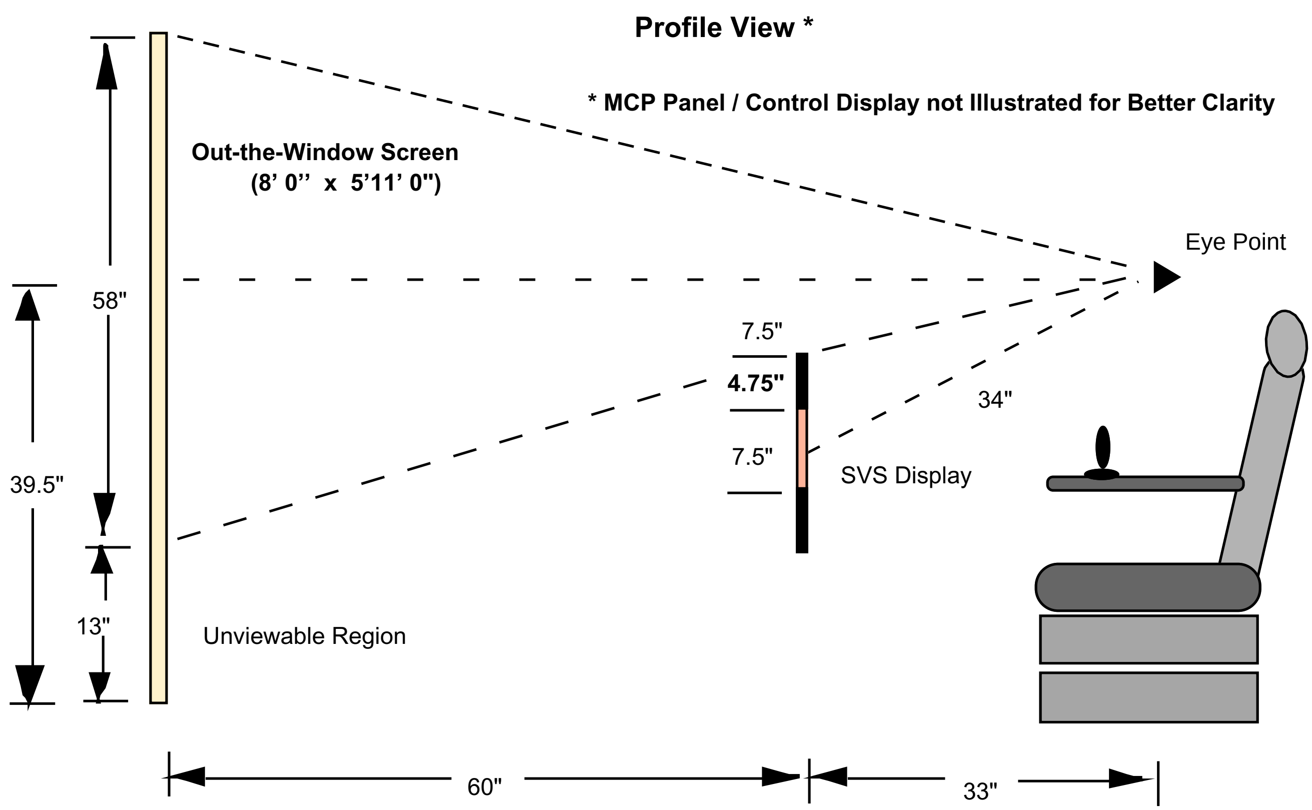
	Sub 3	Sub 4	Sub 5
1. Current position:	Captain	First Officer	Captain
2. Current aircraft operated:	B767/B757	B747-400	B757/767
3. Hours logged on current aircraft:	5000+	1100	800
4. Years flying commercially- Total:	17	10	7
As Captain:	10		4
As FO:	7	10	3
5. Hours logged- Total:	16000	12000	11000
Glass equipped aircraft:	9000	5000	2000
6. Have you ever used a head-up display(HUD):	No	No	Yes
How many hours logged with HUD:			100
7. Have you ever used a terrain awareness display(TAD):	Yes	No	Yes
How many hours logged with TAD:	2000		1500
8. Have you ever flown into Santa Barbara Municipal Airport:	Yes	No	Yes
How many times:	50		4

Schematic of Simulation Set-up

Front View



Schematic of Simulation Set-up



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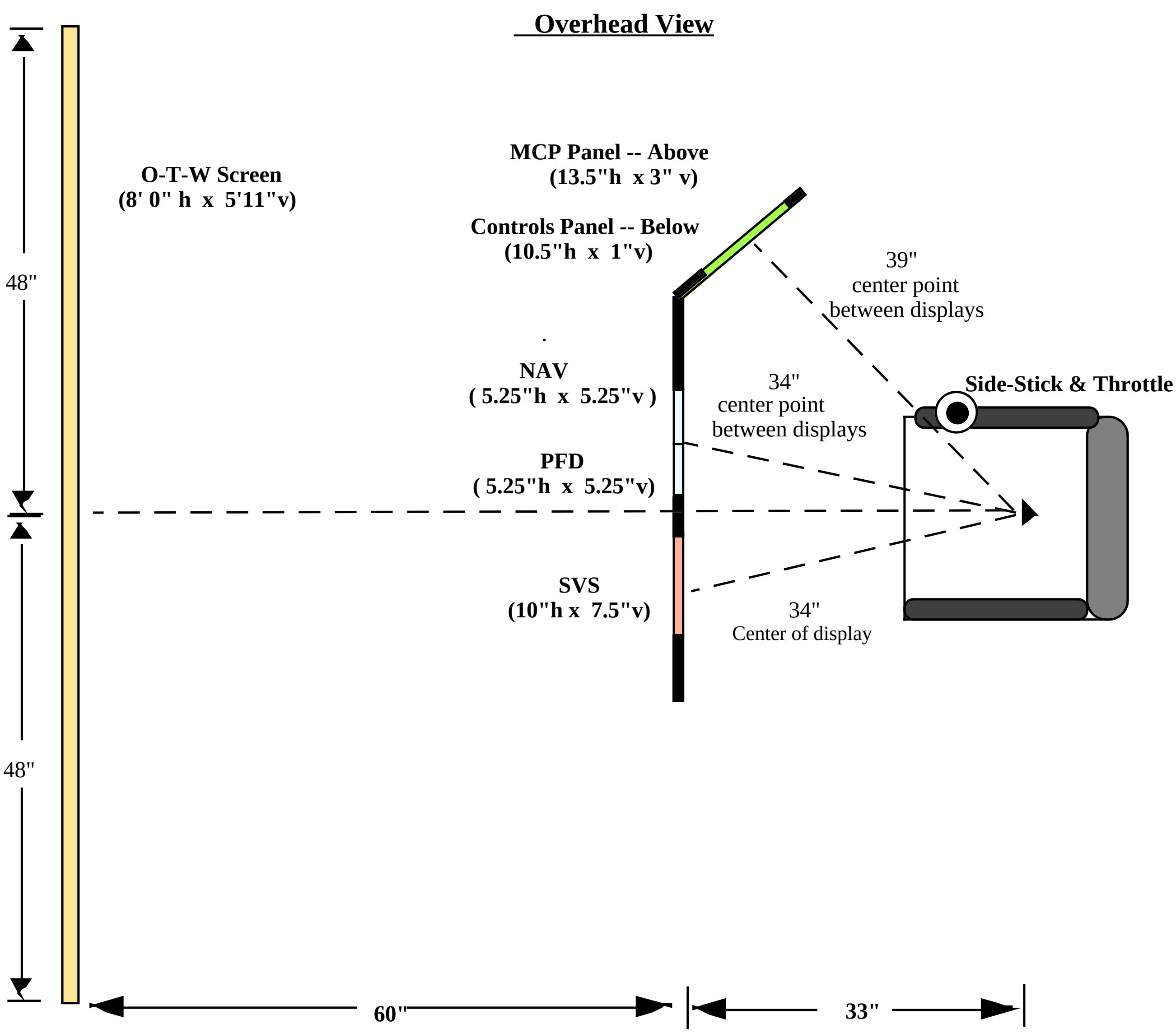
Schematic of Simulation Set-up



<u>Approach Plate</u>